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ABSTRACT

The student materials present lessons about occupations related to environmental control, stationary engineering, and refrigeration. Included are 18 units organized by objective, information, reference, procedure, and assignment. Each lesson involves concrete trade experience where science is applied. Unit titles are: safety and housekeeping, applied physics, basic hand tools, heating systems, stationary engineering and heating equipment, boiler room systems, combustion, combustion equipment, refrigeration, refrigeration equipment, cooling towers and ponds, ventilating systems and accessories, air conditioning, basic electricity, instruments, operation, and service and maintenance. (LJ)

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State of New Jersey
Department of Education
Division of Vocational Education

STATIONARY ENGINEERING
ENVIRONMENTAL CONTROL
REFRIGERATION

SCIENCE MANUAL - 1

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State of New Jersey
Department of Education
Division of Vocational Education

STATIONARY ENGINEERING
ENVIRONMENTAL CONTROL
REFRIGERATION

Science Manual I

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BUILDING 4103 – KILMER CAMPUS
NEW BRUNSWICK, NEW JERSEY

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INTRODUCTION

These lessons relate science instruction to the fields of Stationary Engineering, Environmental Control, and Refrigeration. The lessons are brief, but they include a wide range of activities in which science is applied to trade activities. A specific class or student may not be able to study all of the lessons; the instructor may wish to select only certain lessons from the wide range of lessons presented. Each lesson involves concrete trade experiences where science is applied.

Mathematics is also needed as science is applied to these trade areas. The following lessons also involve mathematical problems used in these trade areas:

III A - 2 Pressure - Force Relationship
III A - 4 Pressure Conversion Factors
III B - 2 Force and Distance Applied to Work
III C - 2 Horsepower
III E - 3 Temperature Conversion
III E - 6 Mechanical Equivalent Conversions
III F - 2 Solving Pressure Problems
III G - 2 Solving Pressure - Volume Problems
III H - 2 Solving Pressure - Temperature - Volume Problems
VI D - 2 Use of Force in Reciprociating Pumps
VII B - 2 Fuel Oil Measurement
VIII C - 2 Theoretical Combustion Air Requirements
XV A - 3 Solving Electrical Power Problems
XV B - 2 Series Circuits
XV B - 3 Parallel Circuits
XV B - 4 Series - Parallel Circuits

Objective: Upon completion of this lesson, the student will be familiar with duties, opportunities, and obligations of stationary firemen and stationary engineers.

Information: What is a stationary engineer? Jokingly, we say he is an engineer who remains stationary – moving only in extreme emergency. Well that's not quite the whole story. A stationary engineer is responsible for supplying us with the electricity we need. Remember the blackout in New York City in November 1965. It seemed as if the world had come to an end. He supplies us with the water we need for washing and drinking; without it we would surely perish. He supplies us with the gas to heat our homes and for cooking. Backyard cookouts are fun, but not for every meal. Ask your mother. He is even responsible for the sanitary disposal of sewage. A city without sewage disposal would not be a city for long. He turns the wheels of industry with the steam, water, electricity and gas he supplies. The stationary engineer is a very important man in our world of technology. Without him, we would return to the dark ages. Let's look at some basic trade information about stationary engineering.

I. **Trade information**

A. Almost any type of industrial plant requires steam either for processing or heating. This opens quite a large field for the prospective engineering student. Plants, large and small, must comply with certain regulations and standards set up by the State, mainly that any boiler carrying more than 15 pounds of steam shall be operated by a licensed fireman.

B. This school is in the heart of a large industrial area where many large plants are located.

C. **Duties of a fireman**

1. A fireman is responsible for the safe and efficient operation of the boiler room. Boilers are dangerous in the hands of an untrained person. If they are not handled properly, they can cause serious damage and loss of life. That is the reason the State requires that men handling this type of equipment pass examinations showing they are qualified to handle the job.
2. The boiler room is the heart of any plant. Without the boiler room, the plant is dead.
3. The boiler room has three regular shifts and one relief shift. They are usually set up in the following manner:
   a. Chief engineer: works days, five days a week; and on call 24 hours a day, seven days a week.

   b. Eight-to-four shift: one engineer, one fireman, and one oiler or one boiler room assistant.
   c. Four-to-twelve shift: same crew as above.
   d. Twelve-to-eight shift: same crew as above.
   e. Relief shift: same crew as above.

4. The fireman works eight hours a day; he eats his lunch on company time.

5. Once a fireman relieves the previous shift, he is required by law to remain in the boiler room until he is properly relieved. He cannot walk off the job after his eight hours are up unless he is relieved by a fireman. That brings up the question of the fireman's reliability:
   a. He must be a sober person.
   b. He must be conscientious.
   c. He must keep cool in an emergency.
   d. He must understand his job and know how to handle any emergency that might endanger the boilers, the plant, or the auxiliary equipment.
   e. He must be on the job at least fifteen or twenty minutes beforehand so he can check his equipment before relieving the watch before him.

D. **Working conditions**

1. Firemen in some plants work a rotating shift which means working days 8 to 4, afternoons 4 to 12, and nights 12 to 8 a.m. Other plants work steady shifts and the firemen must acclimate himself and his family to these conditions.
2. The fireman is required to keep a neat, clean boiler room.
3. Most large plants will have a two week shut-down period when there is no steam in the plant at all. During this time the boiler room crew will make necessary minor repairs, pack valves, and clean the boilers internally and externally. The boilers are inspected once a year by a boiler inspector; it is part of the fireman's duty to prepare boilers for inspection.

E. **Security**

1. A fireman's job is as secure as he makes it. Once he has learned his plant, he has a job for the rest of his life. He must do something very serious to get discharged.
2. A good fireman is worth his weight in gold, and a chief engineer will do all in his power to keep him on the job because it means that he (the chief) can go to bed at night and sleep without worrying about the plant.
3. During times of layoffs, the boiler room crew is the last to be laid off. As long as one department in the plant is operating, they will need the boiler room. In some cases, a plant that lays off for a short time will keep its boiler room crew on to maintain the plant in operating condition and safe from fire and freeze-ups.

4. In times of a strike, the boiler room crew will very often work right through with the union's sanction because the union must agree always to leave the plant in a safe condition before calling a strike.

F. **Advancement**

The fireman who will apply himself and learn his job can, without too much trouble, raise his license to that of a stationary engineer. He can then raise his engineer's license from blue seal to red seal to gold seal and become a chief engineer, a job with responsibility and good pay.

II. Purpose of this course

A. This course has been set up because there is a definite need for good firemen in industry. Until now a man had only to work in the boiler room for a year or so, be coached on a few basic questions, and after three or four attempts, pass his fireman's license. Then a new fireman was born. It was a very haphazard way. The days of a fireman needing a strong back and a weak mind have passed with the horse and buggy. The modern boiler room is full of electronic equipment which requires intelligent handling.

B. In this area there is an association known as the National Association of Power Engineers. Many of the Chief Engineers of the larger manufacturing plants belong to this group: for example, Alcoa, Bendix, Wrights, and many others. They are very interested in this course and have helped to set it up. Incidentally, the association is not restricted to Chief Engineers; anyone who is interested in bettering himself and holds a fireman's or engineer's license may make application to join.

Procedure: Read the trade information presented and be prepared to discuss it in class.

Assignment:

1. Look through your daily newspaper and one Sunday paper. Cut out all job opportunities listed for stationary engineers.
2. Check with an employment agency for job opportunities for stationary fireman or stationary engineer.

Objective: Upon completion of this lesson, the student will be familiar with the job opportunities in the field of environmental control.

Information: The term, environmental control, should be some indication of just how large this field is. It means that we are trying to control our surroundings, not only in our homes, but where we work and play. Man is no longer willing to go along with nature. He isn't willing to be hot in the summer, cold in the winter, or suffer with allergies due to dust or pollen in the air. Technology has made it possible to create the environment man chooses to live in. This means the total conditioning of the air. An environmental control specialist must be familiar with heating, cooling, filtering, humidifying, and dehumidifying the air. He must have an understanding of installation and servicing of the equipment necessary to accomplish this feat.

The student entering this field not only has the opportunity of working with small contractors, but also the possibility of employment with equipment manufacturing concerns as field representative or trouble shooter. He could also open his own business installing and servicing this type of equipment.

Industry is looking for mechanics. The pay is good and the job is steady; it is not seasonal work as some trades are.

Reference: Trade journals on environmental control

Procedure: Read the trade information presented and be prepared to discuss it in class.

Assignment: Look through your daily newspaper and one Sunday paper. Cut out all job opportunities related to the field of environmental control.

Objective: Upon completion of this lesson, the student will be familiar with the job opportunities in the field of refrigeration.

Information: What is refrigeration? Although refrigeration plays an important part in our daily lives, we know little or nothing about what it means in job skills or opportunities. In our modern day-to-day world, refrigeration plays a most important part as it protects our food from spoiling. It allows us to freeze foods for long periods of storage, and it is the basis by which we can cool our homes and commercial building. The refrigeration field has many openings for qualified mechanics and technicians. Industrial processes require refrigeration. Candy companies need it to coat their candy fillings with chocolate. Ice cream just wouldn't be possible without it. You couldn't make wax paper and oh so many other things that we take for granted. The refrigeration student must have an understanding of electricity, controls, pipe fitting installation, and servicing. It opens a field in industrial plants, and the manufacturers of refrigeration equipment need sales representatives and field service and trouble shooting technicians. This is not seasonal work; technological advances of recent years make refrigeration a must during winter and summer.

References: Trade journals in refrigeration

Procedure: Read the trade information presented and look through the trade journals available. Be prepared to discuss what you have read.

Assignment:

1. Look through your daily newspapers and one Sunday paper. Cut out all job opportunities related to the refrigeration field.
2. Look around your town and list the places where a person with a refrigeration background might be needed.

No Related Science – Student responsibility and safety rules will be taught in shop.

Fire Prevention and Housekeeping — Assignment II-A-2

Objectives: Upon completion of this lesson, the student will:

1. Know how to handle combustible material.
2. Be able to identify the three classes of fires.
3. Identify the types of extinguishers and know what types of fires they are used on.

Information: What is meant by a combustible material? Right! Something that will burn. We should be aware of what is needed to start a fire in order for us to be able to put that fire out. This is a switch because after this lesson we will spend the next three years teaching you how to start a fire and keep it burning. Fire is one of man's best friends, but out of control it is one of his enemies.

A fire will start if you have three things:

1. Fuel – combustible material
2. Heat – enough for combustible material to reach its ignition temperature
3. Oxygen – to support combustion

Remove any one of these, and the fire goes out.

The main ingredient is the combustible material. That's why it is necessary to store waste or oily rags in safety containers, and volatile liquids in safety cans. By keeping careful control of the combustible materials in a boiler room, you cut down the danger of fire. We want the fire in the boiler fire box where we can control it, not in the boiler room where we have to fight it.

The three classes of fires are:

1. Class A – wood, paper, rubbish.
2. Class B – oil, gasoline, and paints.
3. Class C – electrical

Reference: *Training Your Fire Brigade*, Walter Kidde

Procedure: After having read the information and studied the reference, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What three things are necessary to start a fire?
2. Describe the three classes of fires we are most likely to encounter.
3. How can a fire be put out?
4. Using five general classes of first aid extinguishers and three classes of fires, make a chart indicating which type of extinguisher is best suited for which class of fire.

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with the units of force and area.
2. Be able to define and understand the term, pressure.
3. Be familiar with a barometer and how it measures atmospheric pressure.
4. Be familiar with the units of pressure

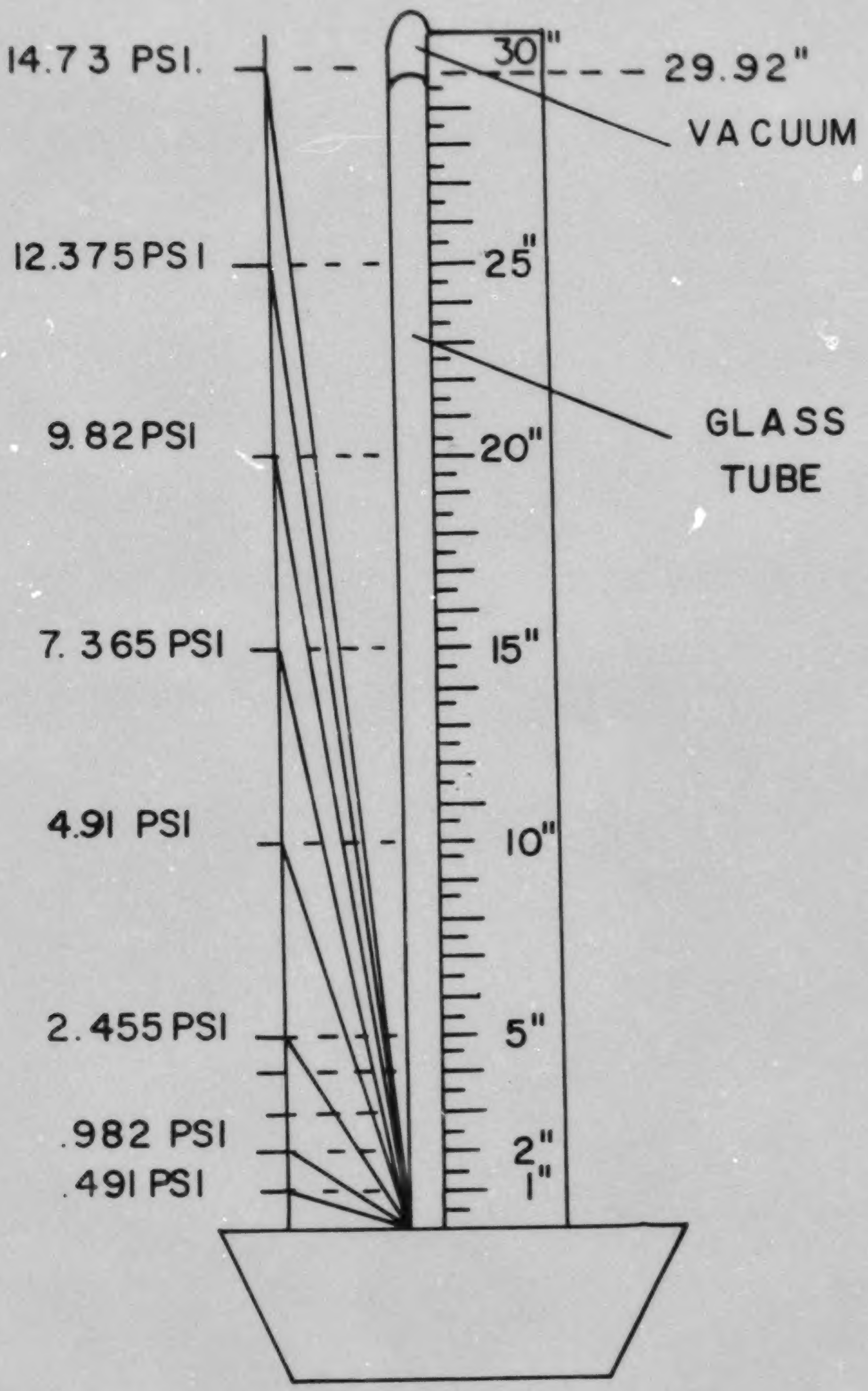
Information: Pressure is defined as a force applied per unit of area. A barometer is an instrument that measures atmospheric pressure. The force that is applied is due to the column of air on the surface of the mercury.

Reference: *Principles of Refrigeration,*Dossat

Procedure: After having studied the listed reference answer the following questions and be prepared to discuss each.

Assignment:

1. Give an example of a force.
2. What is the area of a football field?
3. What is pressure?
4. What unit is pressure expressed in?
5. Describe a barometer.
6. How does one read a barometer?


14.73 PSI.
12.375 PSI
9.82 PSI
7.365 PSI
4.91 PSI
2.455 PSI
.982 PSI
.491 PSI
30"
29.92"
VACUUM
25"
GLASS TUBE
20"
15"
10"
5"
2"
1"

1" MERCURY = .491 PSI

Fig. III-A-1-1

Pressure–Force–Area Relationship Assignment III-A-2

Objective: Upon completion of this lesson, the student will be able to use the pressure–force–area relationship in problem solving.

Information: Pressure is defined as a force applied per unit of area:

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$$

If the force acting on a given area is known, then you can find the pressure.

Example:

1. A force of 1000 pounds is applied to an area of 4 square inches. What is the pressure?

   $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ $\text{Pressure} = \frac{1000}{4}$

   Pressure = 250 pounds per square inch.

2. A force of 1500 pounds is applied to a rectangular area 5″ X 3″. What is the pressure on the surface?

   $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ $\text{Pressure} = \frac{1500}{5 \times 3} = \frac{1500}{15}$

   Pressure = 100 pounds per square inch.

3. A force of 707 pounds is applied to a circular disc 3 inches in diameter. What is the pressure on the surface?
   The area of a circle = .7854 X Diameter^2

   $\text{Pressure} = \frac{707}{.7854 \times 3 \times 3}$ $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$

   Pressure = 100 pounds per square inch.

You can also find the area when the pressure and force are known:

$\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ $\text{Area} = \frac{\text{Force}}{\text{Pressure}}$

Example:

4. The force is 1500 pounds and the pressure is 100 p.s.i. What is the area acted upon?

   $\text{Area} = \frac{\text{Force}}{\text{Pressure}}$ $\text{Area} = \frac{1500 \text{ lbs.}}{100 \text{ p.s.i.}}$ Area = 15 sq.in.

5. The force is 707 pounds, and the pressure is 100 p.s.i. What is the area acted upon?

   $\text{Area} = \frac{\text{Force}}{\text{Pressure}}$ $\text{Area} = \frac{707}{100 \text{ p.s.i.}}$ Area = 7.07 sq.in.

It is also possible to find the force if the pressure and the area are known.

$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \qquad \text{or Force} = \text{Pressure} \times \text{Area}$$

6. Find the force on the bottom of a tank that has base dimensions of 6 feet × 12 feet and has a pressure of 3 p.s.i.

   $F = P \times A \qquad F = 3 \times 6 \times 12 \times 12 \times 12 \qquad F = 31{,}104$ pounds

7. Find the force on a flat head of a steam boiler drum with a pressure of 100 p.s.i. and an area of 1000 square inches.

Procedure: After having read the information and studied the sample problems, do the following assignment.

Assignment:

1. Find the force on a safety valve disc that has an area of 6.25 square inches and is connected to a 250 p.s.i. boiler.
2. A rupture disc on a refrigeration machine has an area of 3 square inches with a pressure of 110 p.s.i. What is the force on that area?
3. Find the area of a flat surface that has a force of 1000 lbs. and produces a pressure of 12 p.s.i.
4. If you have a force of 10,000 pounds and a pressure of 900 p.s.i. what is the area the force is acting on?
5. What is the pressure on the top of a compressor piston if the force is 20,000 lbs. and the area of the piston is 85 square inches?
6. Find the pressure that would be exerted on a circular disc of 3-inch diameter that has a force of 1100 pounds applied to it.

Objectives: Upon completion of this lesson, the student will:

1. Know how pressure gages function.
2. Know how manometers function.
3. Know how bourdon tube gages function.
4. Know what absolute and gage pressure readings mean.

Information: The three common gages used today are the *manometer, bourdon tube* and *diaphragm* types.

The manometer is a simple U-tube that is graduated in inches and is read as so many inches of water (H_2O) or mercury (HG).

The bourdon tube gage operates from pressure being applied to the inside of a closed metal tube. This causes the tube to try to straighten out; that moves a pointer to indicate pressure.

The diaphragm type gage has two chambers separated by a diaphragm. Pressure applied to the diaphragm causes a movement of the gears and the pointer, thus indicating a pressure reading.

Gages normally read 0 p.s.i. at atmospheric pressure; the reading you get is not the absolute or true pressure, but pressure above that due to the atmosphere. We call that reading gage pressure.

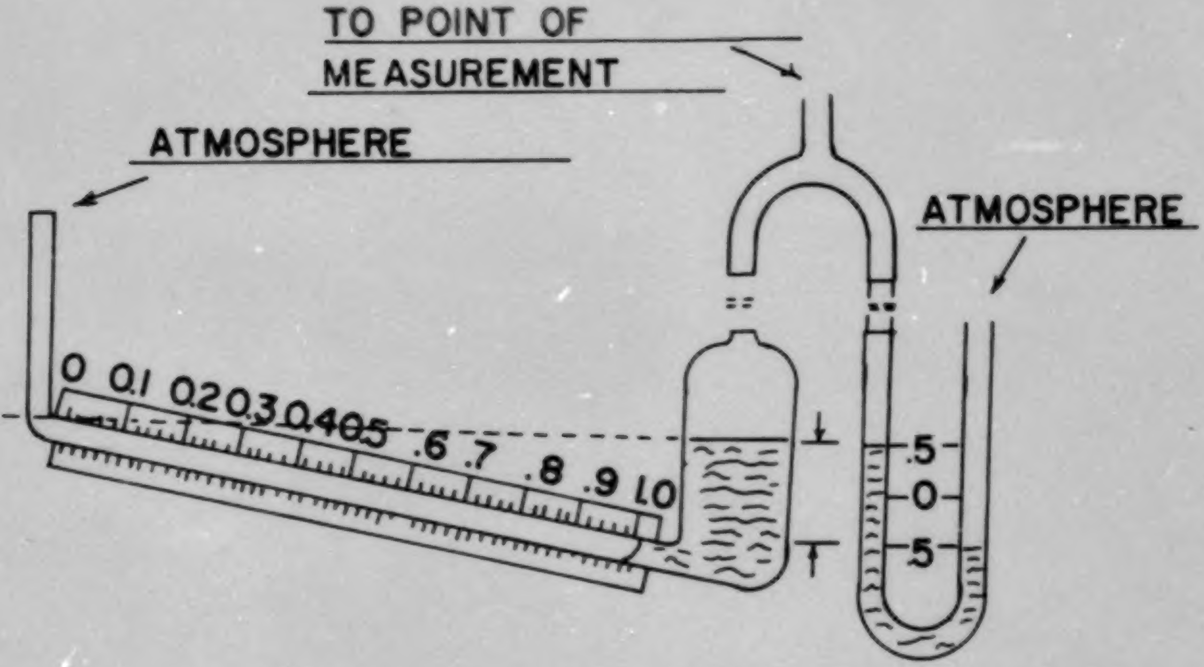
Absolute pressure is a gage reading plus the pressure from the atmosphere, which is normally 14.7.p.s.i. Therefore, we can say abs = gage + 14.7 p.s.i.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After having studied the listed reference, answer the following questions and be prepared to discuss each.

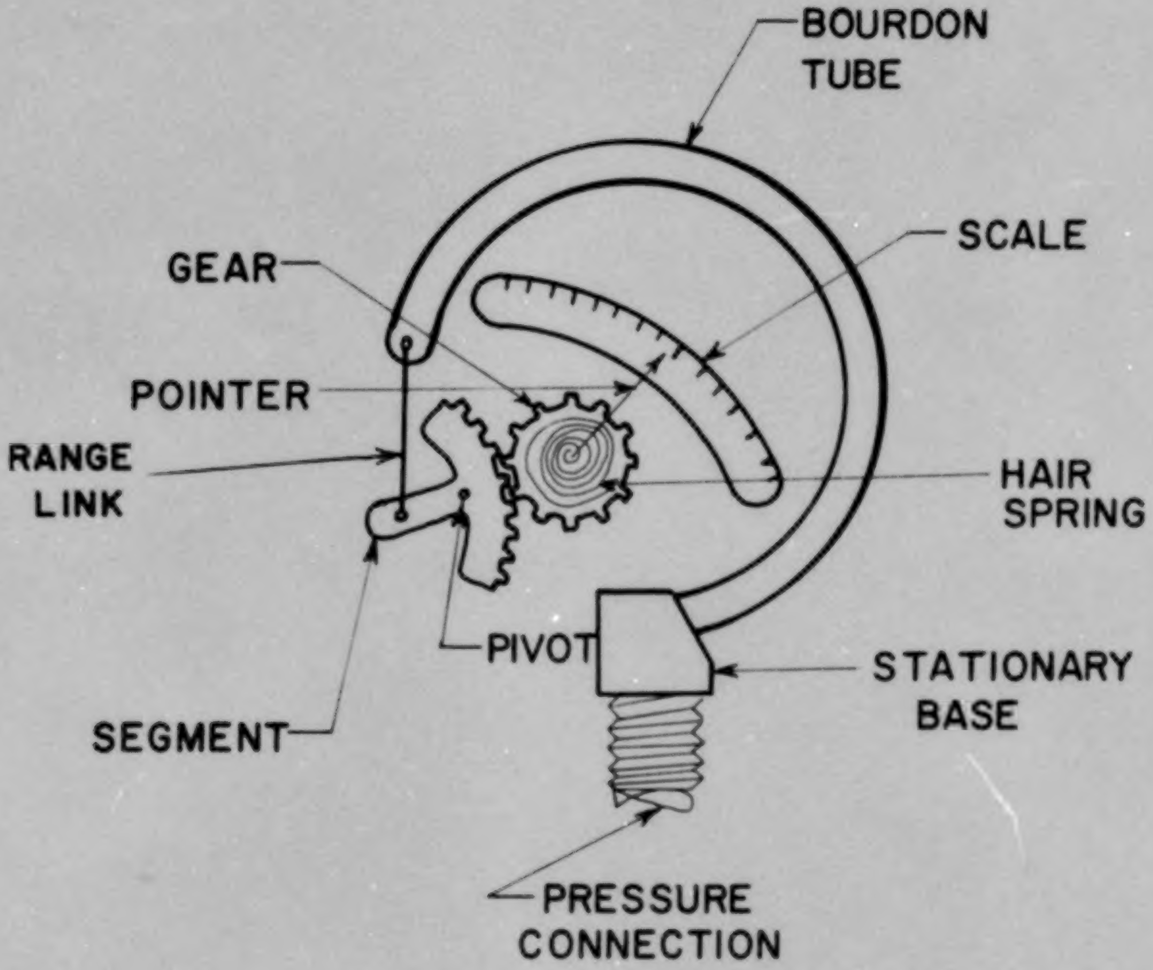
Assignment:

1. What is a manometer and how does it function?
2. What fluids are normally used in manometers? What determines which fluid is used?
3. How do you read a manometer?
4. Describe gage and absolute pressure. Show by a diagram how they compare.
5. Describe a bourdon tube gage and explain how it functions.
6. What are the units that are used to indicate pressure?


TO POINT OF MEASUREMENT
ATMOSPHERE
0
0.1
0.2
0.3
0.4
0.5
.6
.7
.8
.9
1.0
ATMOSPHERE
.5
0
.5

COMPARISON INCLINED DRAFT GAGE
AND U-TUBE GAGE

Fig. III-A-3-1


BOURDON TUBE
SCALE
GEAR
POINTER
RANGE LINK
HAIR SPRING
PIVOT
STATIONARY BASE
SEGMENT
PRESSURE CONNECTION

BOURDON TUBE

Fig. III-A 3-2

Pressure Conversion Factors — Assignment III-A-4

Objectives: Upon completion of this lesson, the student will:

1. Know the pressure conversion factors.
2. Know how to convert from foot head to pounds per square inch.
3. Know how to convert from inches of mercury column to pounds per square inch.
4. Know how to convert from absolute pressure to gage pressure.

Information: In every trade there are certain basic tools that must be used and mastered. The stationary engineering student must master hand tools, but he must also be able to master some basic concepts and make them work for him. At times they are more important than an easyout or pipe wrench.

1. For every vertical foot of water, the pressure at the base of a column is .433 p.s.i.
2. For every vertical inch of mercury, the pressure at the base of a column is .491 p.s.i.
3. Gage pressure is the pressure indicated on the face of a pressure gage. To change gage pressure to absolute pressure, add 14.7 p.s.i. which is atmospheric pressure.
4. A vacuum is sometimes described as an absence of pressure. Actually it is a pressure below atmospheric pressure. Vacuum gages are calibrated in inches of mercury (HG). To convert a vacuum reading to absolute pressure, multiply the vacuum reading by .491 and then subtract it from 14.7 (atmospheric pressure).

Examples:

1. A boiler pressure gage mounted on a panel board is located 30′ below the boiler drum. With no pressure on the boiler, what pressure if any would the gage indicate?

   1 vertical foot = .433 p.s.i.

   30 vertical feet =

   30 × .433 = 12.99 or 13 p.s.i.

2. What pressure would a 29″ barometer indicate?

   One vertical inch of mercury = .491 p.s.i.

   29″ mercury = 29 × .491 = 14.239 p.s.i.

3. A boiler pressure gage reads 150 p.s.i. What would this be in p.s.i.a?

   Absolute pressure (p.s.i.a) = Gage pressure + Atmos. pressure.

   150 + 14.7 = 164.7 p.s.i.a.

4. A fuel oil suction gage reads 7.5 inches of vacuum. What would this be in absolute pressure?

inches of vacuum × .491 =

7.5 × .491 = 3.6825

14.7 – 3.68 = 11.02 p.s.i.a.

Procedure: After you have read the information and studied the examples, do the following assignment.

Assignment:

1. A stand pipe in the engine room is 200 feet tall. What would the pressure gage at its base read if it were:
   a. ½ full?
   b. 3/4 full?
   c. full?
2. A pump is capable of discharging water at a pressure of 80 p.s.i. How high can this pump deliver the water?
3. A column of mercury 15" exerts how much pressure at base?
4. If the pressure at the base of a column of mercury was 9.82 p.s.i., how many inches of mercury would this support?
5. A safety valve on a boiler pops at 150 p.s.i. and resets itself at 160 p.s.i.a. What is the blow back? What is the percent of blow back?
6. A turbine exhausts into a condenser carrying a 29" vacuum. What is the absolute pressure in the condenser?

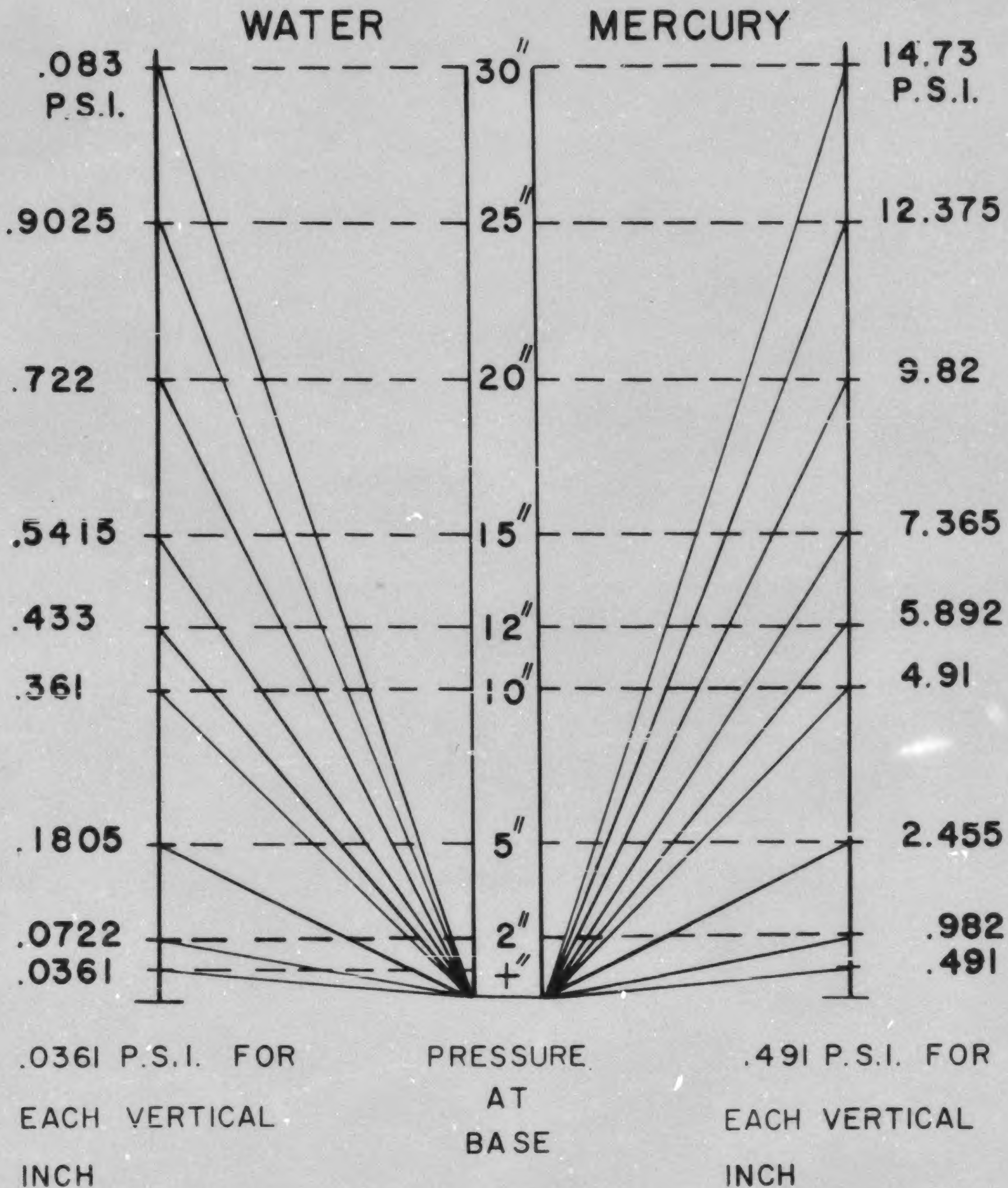
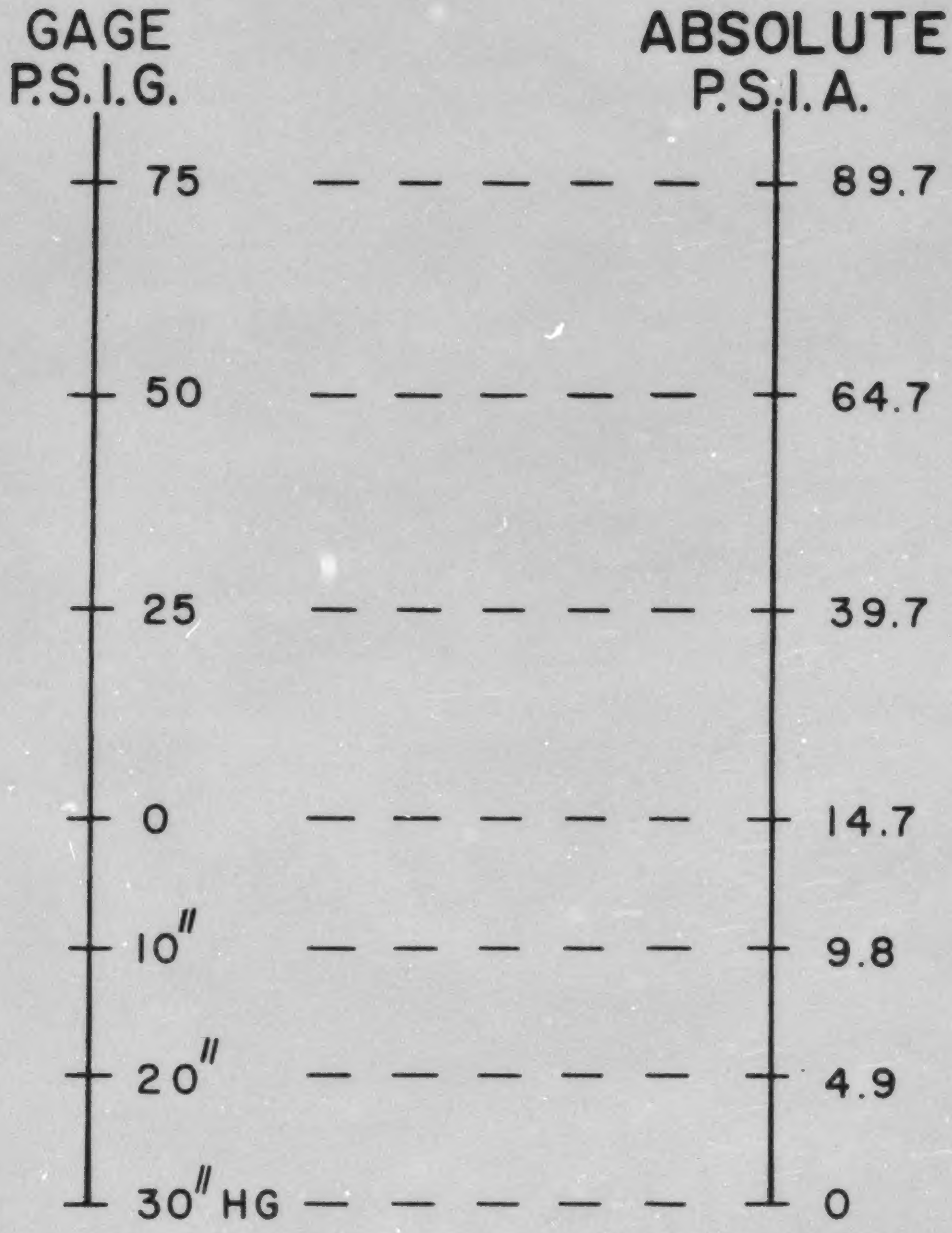

WATER
MERCURY
.083 P.S.I.
.9025
.722
.5415
.433
.361
.1805
.0722
.0361
30″
25″
20″
15″
12″
10″
5″
2″
1″
14.73 P.S.I.
12.375
9.82
7.365
5.892
4.91
2.455
.982
.491
.0361 P.S.I. FOR EACH VERTICAL INCH
PRESSURE AT BASE
.491 P.S.I. FOR EACH VERTICAL INCH

Fig. III-A-4-1


GAGE
P.S.I.G.
ABSOLUTE
P.S.I.A.
75
89.7
50
64.7
25
39.7
0
14.7
10″
9.8
20″
4.9
30″ HG
0

GAGE PRESSURE TO ABSOLUTE PRESSURE CONVERSION CHART

Fig. III-A-4-2

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with the terms, force, and distance as applied to work.
2. Know how to measure the amount of work done.
3. Know which units to use to measure work.

Information: Force is defined as a push or a pull measured in terms of weight (pounds). The units of distance are stated in a linear measure (feet). Work is done when a force acting on a body moves it a distance. The amount of work is the product of the force and the distance moved. The unit of work is the foot-pound and is normally written ft.lb. An example would be: a force of 100 lbs. moves an object 10 ft. The work done would be f X d = 100 X 10 = 1,000 ft.lbs.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. What are the units that express work?
2. Show how these units are obtained.
3. State a simple rule for finding work done when the force and distance moved are known.
4. Set up and solve a problem involving work.

Force and Distance Applied to Work — Assignment III-B-2

Objective: Upon completion of this lesson, the student will be able to figure foot-pounds of work done.

Information: Before the age of machines, man knew how much work he had done by how tired he was. There was never any doubt in his mind. He knew! With machines and the design and building of machines, there had *to be* some way of measuring the output or work or power produced. It had to be a standard that could be used anywhere in the world. That's why we must understand what is meant by work, power, horsepower, boiler horsepower, mechanical equivalent of heat, etc. We will start off with work – how it's measured, how to figure how much work is done, etc.

To do work we must apply a *force*. It may be either a push or a pull, and it will be measured in *pounds*. There will be no work done until the object that the force is being applied to moves a distance. The distance is measured in feet.

Therefore:

Force is a push or pull measured in pounds.

Work involves force and distance.

Distance is measured in feet.

Work = force X distance
= force (lbs.) X distance (ft.)
= ft.lbs.

Example: A force of 100 pounds is applied and moves an object 100 feet. How many foot pounds of work was done?

W = F X D
= 100 lbs. X 100 ft.
= 10,000 ft.lbs.

Procedure: After you have studied the information and example, do the following assignment:

Assignment:

1. How much work would you do if you moved a 500-pound safe a distance of 20 feet?
2. If you exert a 50-pound pull to move a load 10 feet, you do how much work?
3. A freight elevator does 50,000 foot pounds of work while lifting a 3000-pound load. How high did it go?
4. A man moves 2 tons of coal 12 ft. How much work is this in ft.lbs?
5. A man pushes a wheelbarrow a distance of 400 ft. and exerts a pressure of 40 pounds. How much work does he do?

Power — Assignment III-C-1

Objectives: Upon completion of this lesson, the student will:

1. Know the meanings of the terms *power* and *horsepower*
2. Be able to relate power to work and time.
3. Understand the relationship between power and horsepower.

Information: Power is defined as the rate of doing work. The units used are foot–pounds and time. From our previous lessons, we know that work is measured in foot–pounds. If we use minutes as a unit of time, then power will equal work per minute of ft.lbs. per minute.

One horsepower is defined as the power necessary to perform work at the rate of 33,000 ft.lbs. per minute. Putting it another way, every time 33,000 ft.lbs. of work per minute is done, one horsepower was required to do it.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. Define the term *power*.
2. Define the term *horsepower*.
3. How does work and time relate to power?
4. How does power relate to horsepower?
5. State a rule to find horsepower if the amount of work done and the time are known.

Objective: Upon completion of this lesson, the student will be able to figure horsepower problems.

Information: We know from our previous lessons that *work* is equal to *force* × *distance* and is rated in *foot-pounds*. When the unit of time in seconds or minutes is introduced, it becomes the rate of doing work or power. Let us see if we can tie this all together:

Power is the rate of doing work. $\text{Power} = \frac{\text{work}}{\text{time}}$

But work = force × distance
(force in pounds)
(distance in feet)

Power then is equal to foot-pounds divided by time.

$$\text{power} = \frac{\text{foot-pounds}}{\text{time}}$$

It was found by experiment that a horse can lift 550 lbs. 1 foot in 1 second or 33,000 lbs 1 foot in 1 minute. That is where the term horsepower comes from.

It can therefore be stated that 1 mechanical horsepower is equal to 33,000 ft.lbs. of work per minute.

1 mech. hp = 33,000 ft.lbs./min.

Example: 1. An engine does 140,000 ft.lbs. of work in 4 minutes. Find its horsepower.

$$\text{Power} = \frac{\text{work}}{\text{time}}$$

$$= \frac{140{,}000}{4} = 35{,}000 \text{ ft.lbs.}$$

1 hp = 33,000 ft.lbs./min.

$$\frac{35{,}000}{33{,}000} = 1.06 \text{ hp.}$$

Procedure: After you have studied the information and example, do the following assignment:

Assignment:

1. An engine can do 68,000 foot-pounds of work in 2½ minutes. Find its horsepower.
2. What horsepower is needed to lift a 4-ton beam 60 feet in 4 minutes?
3. A pump delivers 40 cu.ft. of water per minute from a depth of 280 ft. Water weighs 62.5 lbs. per cu.ft. Find its hp.
4. Find hp needed for an elevator to lift 4,800 lbs. 220 ft. in 2½ minutes.

Objectives: Upon completion of this lesson, the student will:

1. Know what energy is.
2. Know the difference between potential and kinetic energy.

Information: Energy is required to do work of any kind. We say a body possesses energy if it has the ability to do work. Energy can be in two basic forms: potential or kinetic.

Potential energy is the energy a body possesses due to its position or shape. Examples of potential energy would be: a weight held above a floor or a slingshot in a firing position. Both possess potential energy. One is because of location or position, and the other is because of shape.

Kinetic energy is the energy a body possesses due to its motion. An example would be a moving train. Energy is measured in foot-pounds. This can be visualized if you think of energy as stored work.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. What is energy?
2. What is potential energy?
3. What is kinetic energy?
4. How are work and energy related?
5. What units are used to measure energy?
6. Give an example of each form of energy and explain why you think it is of that form.

Objectives: Upon completion of this lesson, the student will:

1. Recognize heat as a form of energy.
2. Recognize that heat or removal of heat can effect the state of a substance.

Information: Heat is a form of energy. We can understand this if we think of the molecules in a substance being in motion. But to have motion the molecules must possess energy, and energy due to motion is kinetic energy.

If we add heat to this substance, we would cause the molecules to increase their velocity. This would show an increase in energy.

If we remove heat, the opposite effect would take place. We can now say that heat causes molecular motion.

There are three states of a substance: solid, liquid, vapor or gaseous. For example: water when it is solid is ice; when it is liquid it is water; when it is gas it is steam. The change into or from one state into another requires the addition or removal of heat. An example is when you add heat to ice, it changes into water. If you continue to add heat, it will turn into steam. The opposite is also true.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each:

Assignment:

1. What is heat?
2. Describe how heat causes molecular motion.
3. What are the effects when heat is applied to a substance?
4. How many states can a substance be in?
5. Give an example of a substance going from a solid to a gas.

Measurement of Heat — Assignment III-E-2

Objectives: Upon completion of this lesson, the student will:

1. Be able to read the scales used on thermometers.
2. Know what temperature is.
3. Know what British thermal unit is.
4. Know the difference between latent and sensible heat.

Information: The thermometers used in engineering have Fahrenheit or Centigrade scales. Thermometers measure the intensity of heat, *not* the quantity of heat.

A British thermal unit (B.t.u.) is the unit used to measure the quantity of heat. A B.t.u. is defined as the heat necessary to change the temperature of one pound of water one degree Fahrenheit.

Sensible heat is heat that will change the temperature of a substance but not its state. An example would be if you added heat to water and the temperature changed from 45° to 55°. You would have added sensible heat.

Latent heat is heat that will change the state of a substance without a change in temperature. An example would be that when water starts to boil, if you continue to add heat, the water changes to steam but the temperature does not change.

Sensible heat can be added or removed in the solid, liquid or the gaseous state.

Latent heat can be added during a change from a solid to a liquid, or during a change from a liquid to a gas.

The removal of heat would cause the opposite effect to take place.

Latent heat of fusion is the heat necessary to change the state of one pound of a substance from a solid to a liquid.

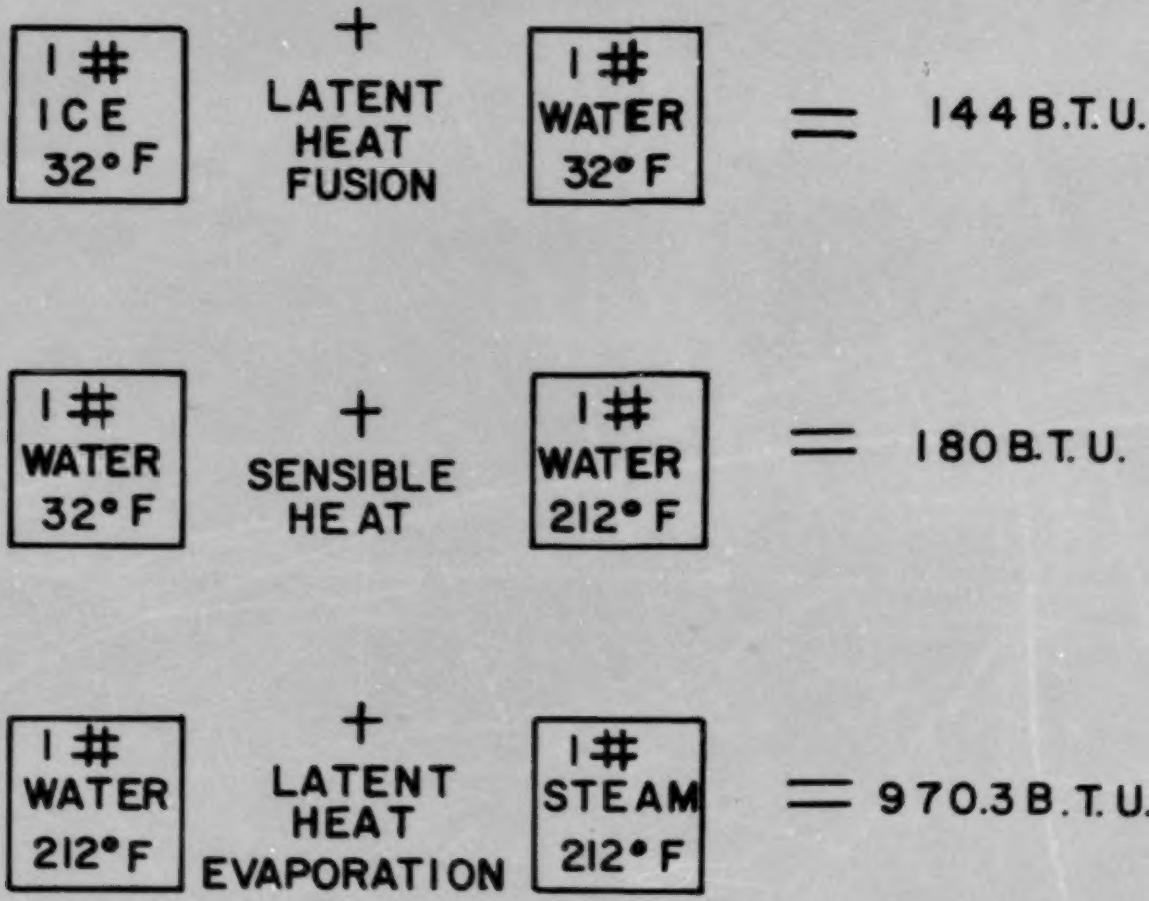
Latent heat of vaporization is the heat necessary to change the state of one pound of a substance from a liquid to a gas.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. Define the term *British thermal unit* (B.t.u.).
2. Explain latent heat of fusion.
3. Explain latent heat of evaporation.
4. What is temperature?
5. Explain the two basic systems used for temperature measurement.
6. What is meant by absolute temperature?
7. Define sensible heat.
8. What is meant by the terms *intensity of heat* and *quantity of heat?*


1 #
ICE
32° F
+
LATENT
HEAT
FUSION
1 #
WATER
32° F
=
144 B.T.U.
1 #
WATER
32° F
+
SENSIBLE
HEAT
1 #
WATER
212° F
=
180 B.T.U.
1 #
WATER
212° F
+
LATENT
HEAT
EVAPORATION
1 #
STEAM
212° F
=
970.3 B.T.U.

BTU CHART

Fig. III-E-2-1

Temperature Conversion — Assignment III-E-3

Objectives: Upon completion of this lesson, the student will be able to:

1. Convert °F to °C.
2. Convert °F to Absolute Scale.
3. Convert °C to °F.
4. Convert °C to Absolute Scale.

Information There are times when it is necessary to convert Fahrenheit to Centigrade or Centigrade to Fahrenheit. It is also necessary to be able to convert Fahrenheit and Centigrade to Absolute Temperature in order to solve certain problems. Looking at the attached sketch we see that between the freezing point and boiling point there are 100° on the Centigrade scale and 180° on the Fahrenheit scale. Therefore, 180° F is equal to 100° C. If we were to divide both by 10, we would have a smaller ratio of 18 F degrees being equal to 10 C degrees (or 1.8 to 1). If we multiply Centigrade degrees by 1.8 we would have the corresponding number of degrees Fahrenheit. However, since 32° F is equivalent to 0° C we would have to add 32° in order for the reading to correspond on both scales. This leaves us with the following formulas:

$$°F = (°C \times 1.8) + 32 \quad \text{or} \quad °C = \frac{°F - 32}{1.8}$$

Examples:

1. What would 60° Centigrade be on the Fahrenheit scale?

$$\begin{aligned} °F &= (60 \times 1.8) + 32 \\ &= 108.0 + 32 \\ &= 140° \text{ F} \end{aligned}$$

2. What would 180° F be on the Centigrade scale?

$$\begin{aligned} °C &= \frac{180 - 32}{1.8} \\ &= \frac{148}{1.8} \\ &= 82.22 °C \end{aligned}$$

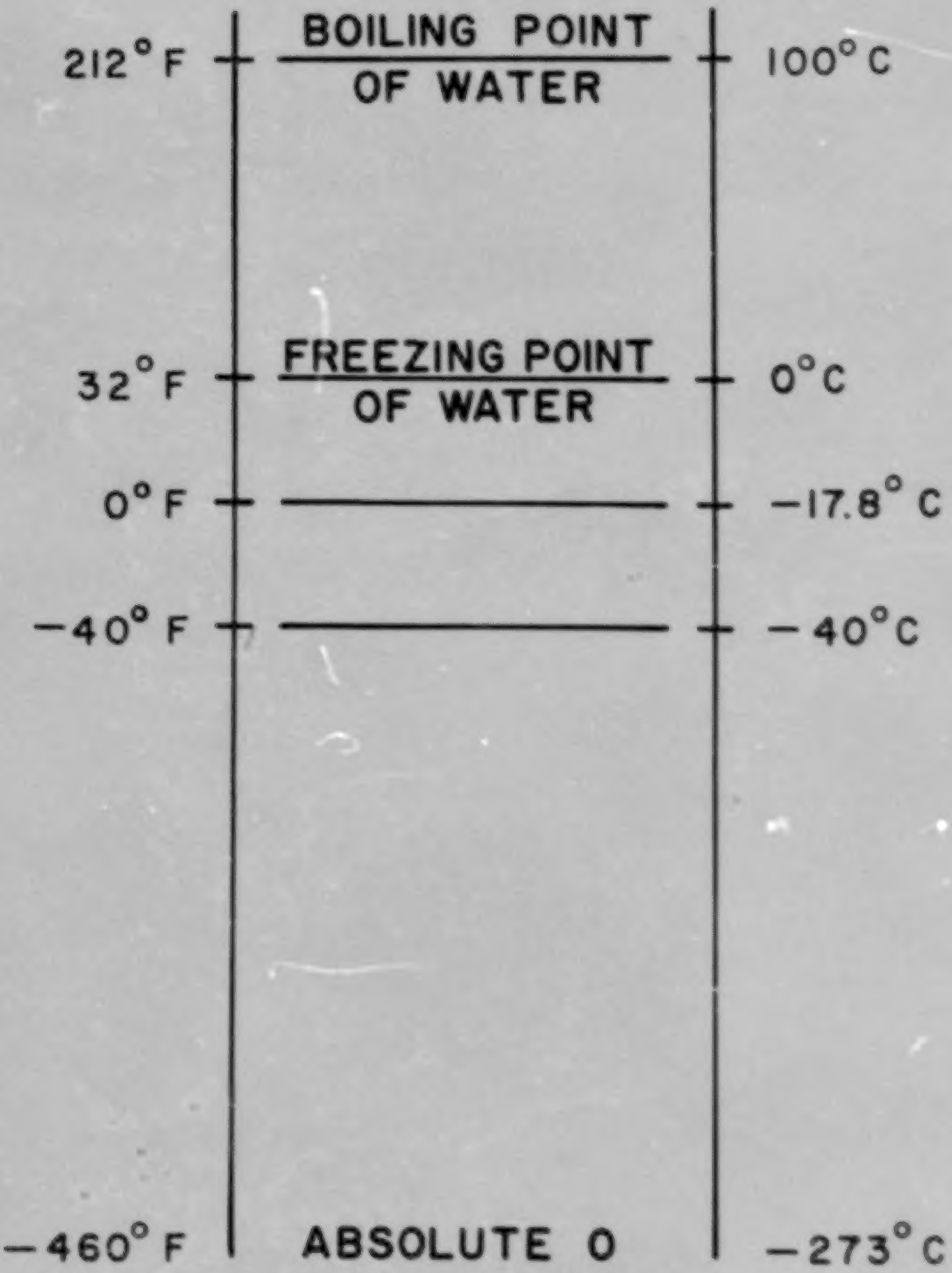
To convert a reading on the Fahrenheit scale to Absolute Temperature, add 460° on the Centigrade scale and add 273°.

Procedure: After you have read the information and studied the examples, do the following problems:

Assignment: Convert the following to degrees Fahrenheit or degrees Centigrade as indicated:

	Centigrade		Fahrenheit
1.	32°	1.	
2.		2.	35°
3.	45°	3.	
4.		4.	96°
5.	40°	5.	
6.		6.	20°

Convert the answers above to Absolute degrees.


212° F
BOILING POINT
OF WATER
100° C
32° F
FREEZING POINT
OF WATER
0° C
0° F
−17.8° C
−40° F
−40° C
−460° F
ABSOLUTE 0
−273° C

TO CONVERT A READING ON F SCALE TO ABSOLUTE TEMPERATURE, ADD 460°; ON C SCALE, ADD 273°

Fig III-3.1

Transmission of Heat — Assignment III-E-4

Objective: Upon completion of this lesson, the student will be able to describe three methods of heat transmission and give examples of each.

Information: Heat flows from one substance to another if a temperature difference exists. It flows from the high temperature to the lower one. The rate of heat transfer is proportional to the temperature difference between the two substances.

There are three methods of heat transfer: conduction, convection, and radiation.

Conduction occurs when molecules come into direct contact with each other and energy is passed from one to the other. If you heat the end of a metal rod, heat will flow by conduction to the other end. By heating the end of the rod, you make the molecules move faster. They in turn came into contact with molecules next to them and gave up some of their energy. This continues until the rod has a uniform temperature along its length.

Convection takes place when heat is transferred by currents in a fluid. In a pot of water if heat is applied at the bottom, the warm water rises and is replaced by cooler water. This sets up a current that continues as long as heat is being applied. Air currents act in the same way. The air above a radiator is warm and will rise, and is replaced by cooler air from the bottom.

Radiation takes place when heat is transferred by a wave motion. Heat reaches the earth from the sun by radiation. When you open a furnace door you feel the heat from the fire immediately. This also is by radiation.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. Explain the movement of heat.
2. What are the methods of heat transmission?
3. Explain each method of heat transmission.
4. How is heat from the sun transmitted?
5. How is heat conducted along a metal?
6. Explain how air in a room is heated.

Mechanical Equivalent of Heat — Assignment III-E-5

Objectives: Upon completion of this lesson, the student will be able:

1. To define: mechanical equivalent of heat.
2. To convert heat units (B.t.u.'s) into mechanical units (ft.lbs.).

Information: Heat is a form of energy and is therefore convertible into other forms of energy. From our previous lessons you will recall that mechanical energy was measured in foot-pounds and heat was measured in British thermal units (B.t.u.'s). It has been determined by experiment that one B.t.u. is the equivalent of 778 ft.lbs. of mechanical energy. This is known as the mechanical equivalent of heat.

To convert B.t.u.'s to ft.lbs. you multiply the number of B.t.u.'s by 778.

$$\text{ft.lbs.} = \text{B.t.u.'s} \times 778$$

To convert ft.lbs. to B.t.u.'s you divide total ft.lbs. by 778.

$$\text{B.t.u.'s} = \frac{\text{ft.lbs.}}{778}$$

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. Explain what is meant by the term, *mechanical equivalent of heat.*
2. What is the mechanical equivalent of heat?
3. How do you convert British thermal units into foot-pounds?
4. How do you convert foot-pounds into British thermal units?

Mechanical Equivalent Conversions — Assignment III-E-6

Objectives: Upon completion of this lesson, the student will be able to:

1. Convert B.t.u.'s to foot-pounds.
2. Convert foot-pounds to B.t.u.'s.

Information: It is important that you know that mechanical energy is convertible to heat energy, and that heat energy can be converted to mechanical energy. Let's review some basic facts:

1. Heat is energy.
2. Energy is the ability to do work.
3. The intensity of heat is measured in °F or °C.
4. The amount of heat is measured in B.t.u.'s.
5. A B.t.u. is the amount of heat necessary to raise the temperature of 1 lb. of water 1°F.
6. Force is a push or pull; it is measured in pounds.
7. Work involves force (in pounds) and distance (in feet). When a force is applied and moves an object a distance, work is done.
8. Work is equal to force (in lbs.) X distance (in feet) or foot-pounds.

It has been determined through experiments that one B.t.u. is equivalent to 778 ft.lbs. of mechanical energy. This is known as the mechanical equivalent of heat. It should be quite obvious that to convert B.t.u.'s to foot-pounds, you must multiply B.t.u.'s X 778.

$$\text{Foot-pounds} = \text{B.t.u.} \times 778$$

To convert foot-pounds to B.t.u.'s you divide foot-pounds by 778.

$$\text{B.t.u.} = \frac{\text{Foot-pounds}}{778}$$

Example: The total amount of heat 1 lb. of steam has as it leaves the boiler is 1,200 B.t.u. per pound. What would this be in foot-pounds?

$$\begin{aligned}\text{ft.lbs.} &= \text{B.t.u.} \times 778\\ &= 1200 \times 778\\ &\ 933{,}600 \text{ ft.lbs.}\end{aligned}$$

Procedure: After you have studied the information and sample problem, do the following problems:

Assignment: 1. There are 33,000 ft.lbs./min. in a mechanical horsepower. How many B.t.u.'s is this the equivalent of?

2. Air conditioning units are rated in B.t.u.'s removed per hour. How much work in foot-pounds per hour would a 10,000 B.t.u. unit perform?
3. A ton of refrigeration is the removal of 200 B.t.u.'s per minute or 12,000 B.t.u.'s per hour. In each case how many foot-pounds of work does this represent?
4. 1 boiler horsepower is equal to 34.5 pounds of water evaporated per hour from and at 212°F.

   The latent heat of evaporation is 970.3 B.t.u.'s per pound.
   How many foot-pounds are in a boiler horsepower?

Charles' Gas Laws — Assignment III-F-1

Objectives: Upon completion of this lesson, the student will:

1. Know the volume-temperature relationship of gases when the pressure remains constant.
2. Know the temperature-pressure relationship of gases when the volume remains constant.
3. Know how to apply Charles' Laws.

Information: The relationship between the volume, temperature, and pressure of gases follows definite laws. Charles' First Law is for a constant pressure process. It states: if you heat a gas at a constant pressure, the volume will increase as the temperature increases. A decrease in temperature will have the opposite effect. You would get a decrease in volume. This can be written as:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

where V_1 and T_1 are the volume and temperature of the gas before heating or cooling, and V_2 and T_2 are for after heating and cooling.

Charles' Second Law is for a constant volume process, and states: if you heat a gas at a constant volume, the pressure will increase as the temperature increases. A decrease in temperature would have the opposite effect; you would get a decrease in pressure. This can be written as,

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

where P_1 and T_1 are the pressure and temperature of the gas before heating or cooling and P_2 and T_2 are after heating or cooling.

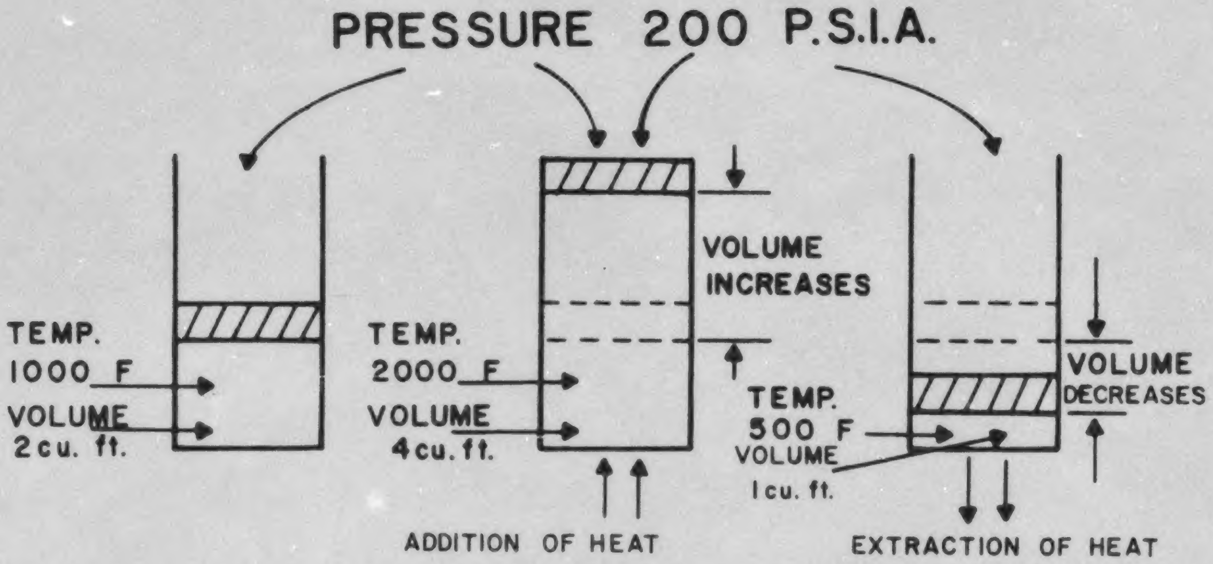
In the above discussion, temperature is measured in (Rankine) absolute degrees. Volume is in cubic feet and pressure is in pounds per square inch absolute.

Reference: *Principles of Refrigeration,* Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each:

Assignment:

1. Explain Charles' First Law (constant pressure).
2. Explain Charles' Second Law (constant volume).
3. Write each law as a formula.
4. Show each of Charles' laws using a diagram or sketch.


PRESSURE 200 P.S.I.A.
TEMP.
1000 F
VOLUME
2 cu. ft.
TEMP.
2000 F
VOLUME
4 cu. ft.
VOLUME
INCREASES
ADDITION OF HEAT
TEMP.
500 F
VOLUME
1 cu. ft.
VOLUME
DECREASES
EXTRACTION OF HEAT

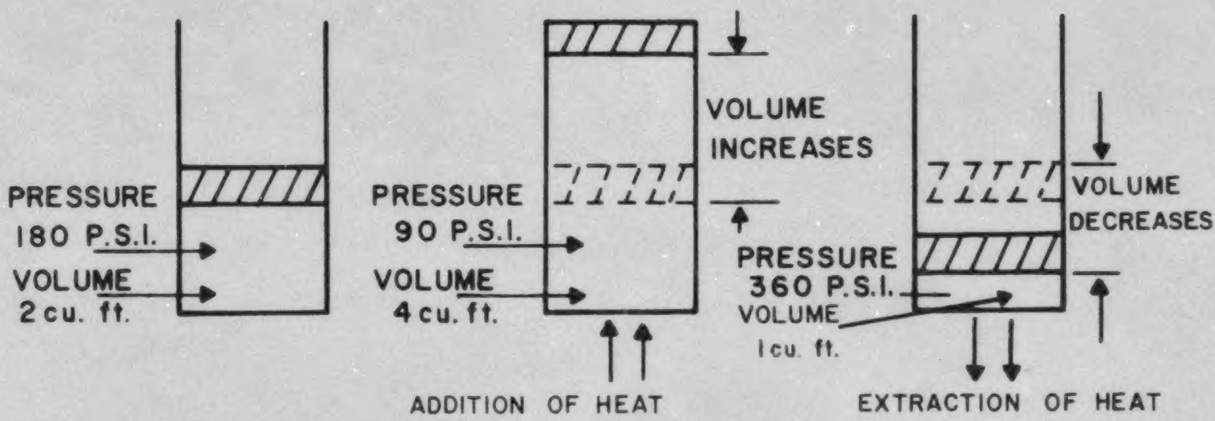
CONSTANT PRESSURE:

1. ADDITION OF HEAT-TEMPERATURE AND VOLUME INCREASES.

2. EXTRACTION OF HEAT-TEMPERATURE AND VOLUME DECREASES.

Fig. III-F-1-1

TEMPERATURE


PRESSURE
180 P.S.I.
VOLUME
2 cu. ft.
PRESSURE
90 P.S.I.
VOLUME
4 cu. ft.
VOLUME
INCREASES
ADDITION OF HEAT
VOLUME
DECREASES
PRESSURE
360 P.S.I.
VOLUME
1 cu. ft.
EXTRACTION OF HEAT

CONSTANT TEMPERATURE:

1. ADDITION OF HEAT-VOLUME INCREASES AND PRESSURE DECREASES.
2. EXTRACTION OF HEAT-PRESSURE INCREASES VOLUME DECREASES.

Fig. III-F-1-2

Objective: Upon completion of this lesson, the student will be able to use Charles' Gas Laws to solve volume and pressure problems.

Information: 1. From your previous lesson you know that if the pressure on a gas is kept constant, its volume will change in direct proportion to its temperature. This can be expressed by using the following formula:

$$\frac{\text{Volume (1)}}{\text{Temperature (1)}} = \frac{\text{Volume (2)}}{\text{Temperature (2)}}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Example: A. What is the volume of 10 cubic feet of gas at 90° F if it is heated to 200° F?

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad V_2 = \frac{V_1 \times T_2}{T_1}$$

Note: Degrees Rankine $V_2 = \frac{10 \times (200 + 460)}{90 + 460}$

$$V_2 = \frac{10 \times 660}{550}$$

$$V_2 = 12 \text{ cu.ft.}$$

Charles' Law also states that if the volume of a gas is kept constant, its pressure will change directly proportional to its temperature, or:

$$\frac{\text{Pressure}_1}{\text{Temperature}_1} = \frac{\text{Pressure}_2}{\text{Temperature}_2}$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Example: B. Find the pressure on a gas tank that has been heated from an initial temperature of 90° F at 100 p.s.i.a. to 200° F.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \qquad P_2 = \frac{P_1 \times T_2}{T_1}$$

Note: Rankine scale. Pressure in absolute

$$P_2 = \frac{100 \times (200 + 460)}{90 + 460}$$

$$P_2 = \frac{100 \times 660}{500}$$

$$P_2 = 120 \text{ p.s.i.a.}$$

Procedure: After you have studied the information and examples, do the following assignment:

Assignment:

1. A gas with an initial temperature of 60° F has a volume of 5 cu.ft. It is heated at a constant pressure to 580° F. What is its final volume?
2. A gas having an initial temperature of 80° F is cooled at a constant pressure until its temperature is 40° F. If the initial volume of the gas is 8 cu.ft., what is its final volume?
3. A gas has an initial temperature of 80° F and a pressure of 30 p.s.i. If the gas is heated until the final pressure is 50 p.s.i. what is the final temperature in ° F when the volume is kept constant?
4. A gas tank has a pressure of 15 p.s.i.a. and a temperature of 50° F. At what temperature would the pressure double?

Boyle's Law

Assignment III-G-1

Objectives: Upon completion of this lesson, the student will:

1. Know the pressure-volume relationship of gases when the temperature remains constant.
2. Know the formula derived from Boyle's Law.

Information: You know that there is a relationship between the volume, temperature, and pressure of gases and that gases do follow definite laws. Boyle's Law is for a constant termperature process, and states: For each change of pressure, there is an inverse change of the volume. This is the same as saying: When the pressure goes up the volume goes down or when the pressure goes down, the volume goes up (increases). This can be written as:

$$P_1 = \frac{1}{V_1} \;;\qquad \text{or} \quad P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{1}{V_2}$$

where P_1 and V_1 is the condition before change and P_2, V_2 is the condition after change. Temperature is constant. In the above discussion, pressure is measured in pounds per square inch absolute. Volume is in cubic feet.

Reference: *Principles of Refrigeration,* Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. What is the formula derived from Boyle's Law?
2. Show and explain Boyle's Law with the use of a sketch.
3. State Boyle's Law as it is written.

Objective: Upon completion of this lesson, the student will solve pressure-volume problems by using Boyle's Law.

Information: Boyle's Law states that the volume of a gas will vary inversely with its pressure if the temperature remains constant. That is:

$$P_1 = \frac{1}{V_1} \cdot \quad P_2 = \frac{1}{V_2} \quad \text{or} \quad P_1 V_1 = P_2 V_2$$

This formula can be used to solve many pressure-volume problems.

Example:

1. If one cubic foot of air is expanded at constant temperature to 2 cubic feet and the initial pressure was 100 p.s.i.a., what is the final pressure?

$$P_1 V_1 = P_2 V_2$$

$$P_2 = \frac{P_1 V_1}{V_2}$$

$$P_2 = \frac{100 \times 1}{2}$$

$$P_2 = 50 \text{ p.s.i.a}$$

2. In the problem above, what will the final volume be if the final pressure is 200 p.s.i.a.?

$$P_1 V_1 = P_2 V_2$$

$$V_2 = \frac{P_1 V_1}{P_2}$$

$$V_2 = \frac{100 \times 1}{200}$$

$$V_2 = .5 \text{ cu.ft.}$$

Procedure: After you have studied the information and examples, complete the following assignment:

Assignment:

1. 5 pounds of air are expanded at a constant temperature from an initial volume of 5 cu.ft. to a final volume of 10 cu.ft. If the initial pressure of the air is 20 p.s.i.a., what is the final pressure?
2. 4 cu.ft. of gas are allowed to expand at a constant temperature from an initial pressure of 8 p.s.i.a. to a final pressure of 2 p.s.i.a. What is the final volume of the gas?

3. Find the initial pressure or volume of the following:

a. P_1 =
V_1 = 15 cu.ft.
P_2 = 45 p.s.i.a.
V_2 = 60 cu.ft.

b. P_1 = 110 p.s.i.a.
V_1 =
P_2 = 55 p.s.i.a.
V_2 = 500 cu.ft.

c. P_1 =
V_1 = 30 cu.ft.
P_2 = 75 p.s.i.a.
V_2 = 90 cu.ft.

d. P_1 = 80 p.s.i.a.
V_1 =
P_2 = 40 p.s.i.a.
V_2 = 250 cu.ft.

4. Find the final pressure or volume of the following:

P_1	= 180 p.s.i.a.	220 p.s.i.a.	225 p.s.i.a.	160 p.s.i.a.
V_1	= 30 cu.ft.	250 cu.ft.	60 cu.ft.	125 cu.ft.
P_2	=		150 p.s.i.a.	80 p.s.i.a.
V_2	= 120 cu.ft.	110 cu.ft.		

General Gas Law

Assignment III-H-1

Objective: Upon completion of this lesson, the student will know what the General Gas Law is.

Information: The combining of Charles' and Boyle's Laws gives the basis for the General Gas Law. The law states that the product of the pressure and the volume divided by the temperature, is equal to the product of the pressure and the volume divided by the temperature. This is the same as saying:

$$\frac{P_1 V_1}{T_1} \qquad \frac{P_2 V_2}{T_2}$$

Before change After change

The unit used will be:

Pressure - p.s.i.a. (pounds per square feet absolute).

Volume - cu.ft. (cubic feet).

Temperature - °R (degrees Rankine).

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each:

Assignment:

1. What is the General Gas Law?
2. What is the General Gas Law formula?
3. How is the gas formula used?

Objective: Upon completion of this lesson, the student will be able to solve pressure-temperature-volume problems using the General Gas Law.

Information: When Charles' and Boyle's Laws are combined, we have what is commonly known as the General Gas Law.

Charles' Laws are expressed as:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \qquad \frac{P_1}{T_1} = \frac{P_2}{T_2}$$

Boyle's Law states that:

$$P_1 = \frac{1}{V_1} \qquad P_2 = \frac{1}{V_2} \text{ or } P_1 V_1 = P_2 V_2$$

Now by combining Charles' Laws and Boyles' Law, we find that:

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

This formula can be used to solve many pressure-volume-temperature problems.

Example: 1. From the following data what is the final gas volume?

$P_1 = 15$ p.s.i.a.
$V_1 = 1$ cu.ft.
$T_1 = 70°$ F
$P_2 = 30$ p.s.i.a.
$V_2 =$
$T_2 = 600°$ F

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{15 \times 1 \times 1060}{530 \times 30} = 1 \text{ cu.ft.}$$

2. Transpose for each unknown and substitute values from Example 1.

$$\frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2}$$

Solve for P_1 $$P_1 = \frac{P_2 V_2 T_1}{V_1 T_2} = \frac{30 \times 1 \times 530}{1 \times 1060} = 15 \text{ p.s.i.a}$$

Solve for V_1 $$V_1 = \frac{P_2 V_2 T_1}{P_1 T_2} = \frac{30 \times 1 \times 530}{15 \times 1060} = 1 \text{ cu.ft.}$$

Solve for T_1 $$T_1 = \frac{P_1 V_1 T_2}{P_2 V_2} = \frac{15 \times 1 \times 1060}{30 \times 1} = 530°\text{R}$$

Solve for P_2 $\quad P_2 = \frac{P_1 V_1 T_2}{T_1 V_2} = \frac{15 \times 1 \times 1060}{530 \times 1} = 30$ p.s.i.a.

Solve for V_2 $\quad V_2 = \frac{P_1 V_1 T_2}{T_1 P_2} = \frac{15 \times 1 \times 1060}{530 \times 30} = 1$ cu.ft.

Solve for T_2 $\quad T_2 = \frac{P_2 V_2 T_1}{P_1 V_1} = \frac{30 \times 1 \times 530}{15 \times 1} = 1060^\circ R$

Procedure: After you have studied the information and examples, complete the following assignment:

Assignment: 1. Solve for unknown values:

	P_1	V_1	T_1	P_2	V_2	T_2
A.	100	5	600	250	10	?
B.	50	10	650	150	?	850
C.	30	25	700	?	15	1400
D.	250	10	?	100	5	600
E.	150	?	1300	50	10	650
F.	?	15	1400	30	25	700

Note: All above values are in absolute - p.s.i.a.
- °Rankine
- cubic feet

2. How many times will a gas expand in a turbine if the initial temperature is 1500°R, the pressure is 500 p.s.i.a., and the volume is 100 cu.ft. At the end the pressure is 1 p.s.i.a. and the temperature is 500°R.

Hint: How many times will the volume change?

Objectives: Upon completion of this lesson, the student will know:

1. The meaning of the term *saturated vapor*
2. The meaning of the term *superheated vapor*

Information: Saturated vapor is a vapor at a temperature that corresponds with its pressure. Any removal of heat from the vapor would cause a portion of the vapor to turn back into the liquid state. For an example: Water is heated and starts to boil at 212° F at zero p.s.i. pressure. The steam leaving the water is also at 212° F and will remain so unless the pressure is changed. (See Fig. III-I-1-1, saturated vapor.)

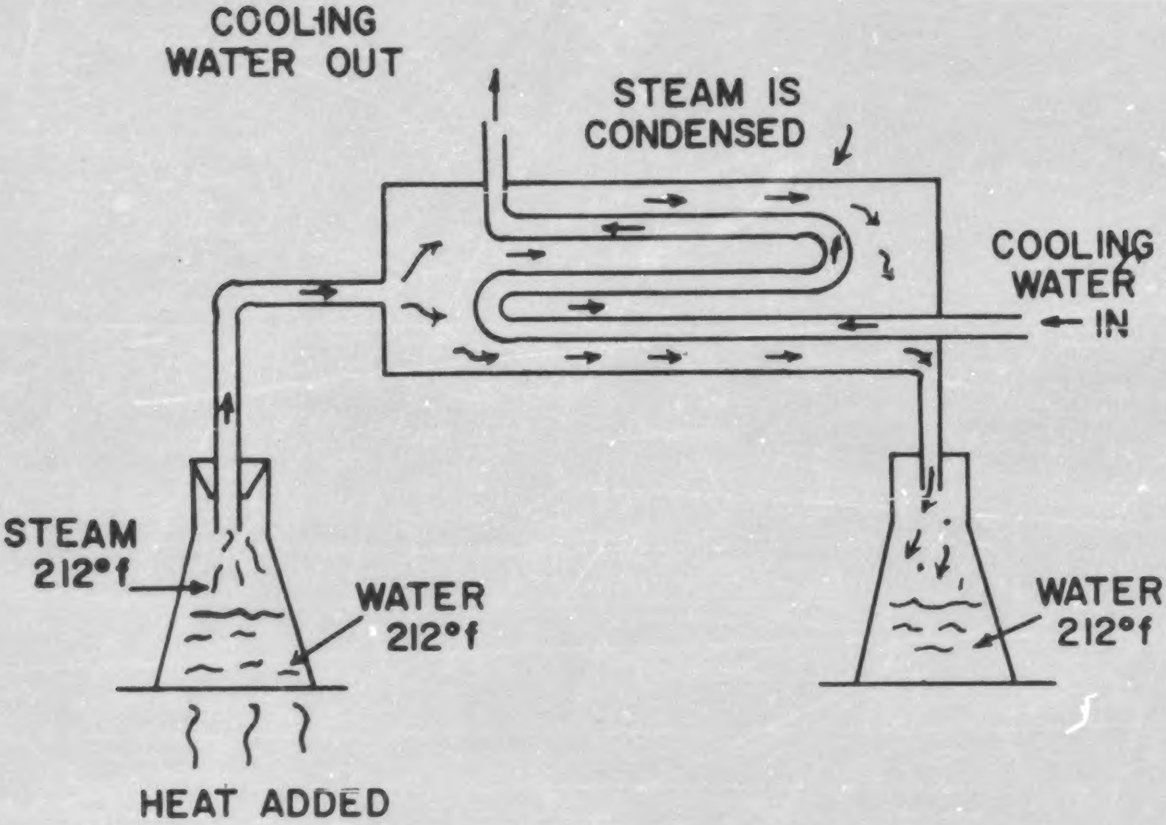
Superheated vapor is a vapor that is at a temperature above its corresponding pressure. Heat has been added to the vapor after it is removed from its liquid. An example of this would be: If you took the saturated steam vapor in part one and put it through a heater to add heat, you would increase its temperature but not its pressure. You would therefore have superheated steam. (See Fig. III-I-1-2, superheated vapor.)

Reference: *Principles of Refrigeration*, Dossat

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each:

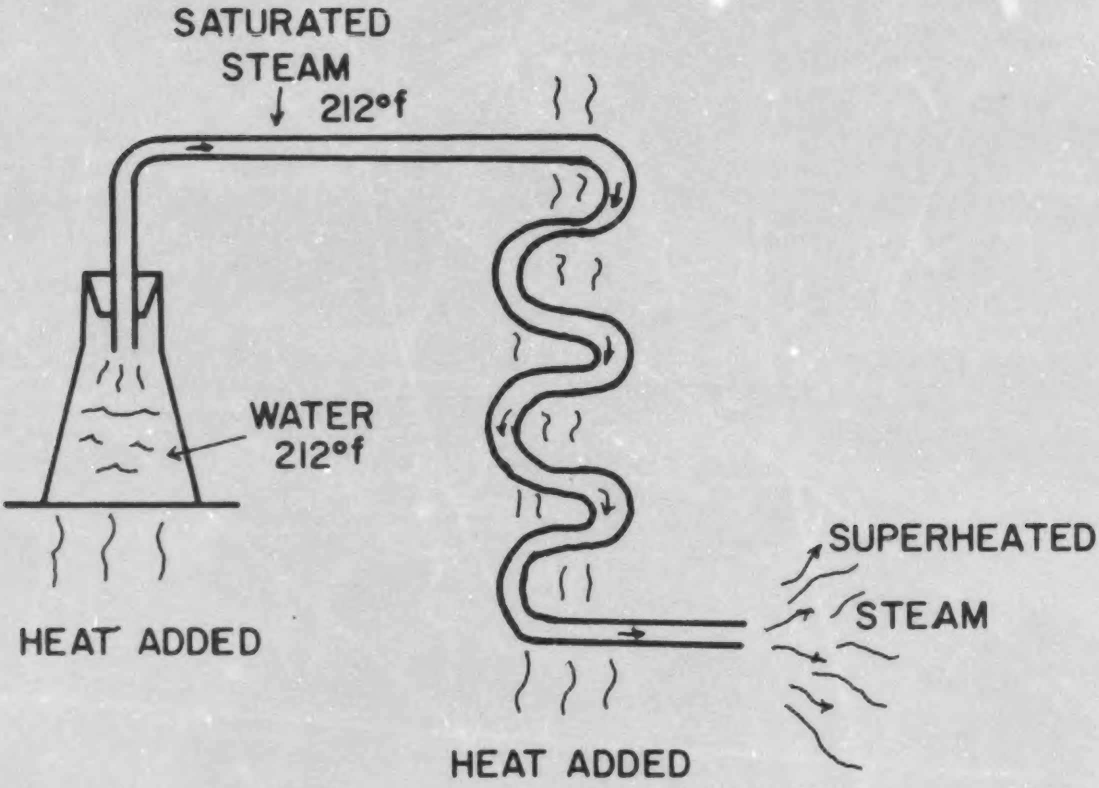
Assignment:

1. What is the saturation temperature of water vapor at atmospheric pressure?
2. What is meant if one says that a vapor is saturated?
3. What is superheated vapor?
4. How can you remove superheat from steam?
5. Show with the use of a sketch how you could get saturated steam and superheated steam.


COOLING WATER OUT
STEAM IS CONDENSED
COOLING WATER IN
STEAM 212°f
WATER 212°f
WATER 212°f
HEAT ADDED

SATURATED VAPOR

Fig. III-I-1-1


SATURATED STEAM
212°f
WATER 212°f
HEAT ADDED
SUPERHEATED STEAM
HEAT ADDED

SUPERHEATED VAPOR

Fig. III-I-1-2

No Related Science. Basic tools will be thoroughly licensed in the shop.

Suggested film: *A.B.C. of Hand Tools*

Objective: Upon completion of this lesson, the student will know how a basic steam heating system works.

Information: The purpose of any steam heating system is to change the chemical energy in the fuel to heat energy in the steam. In order to accomplish this, the steam system must be able to produce steam in large quantities. Using Schematic V-A-1-1, let us trace out a basic steam heating system.

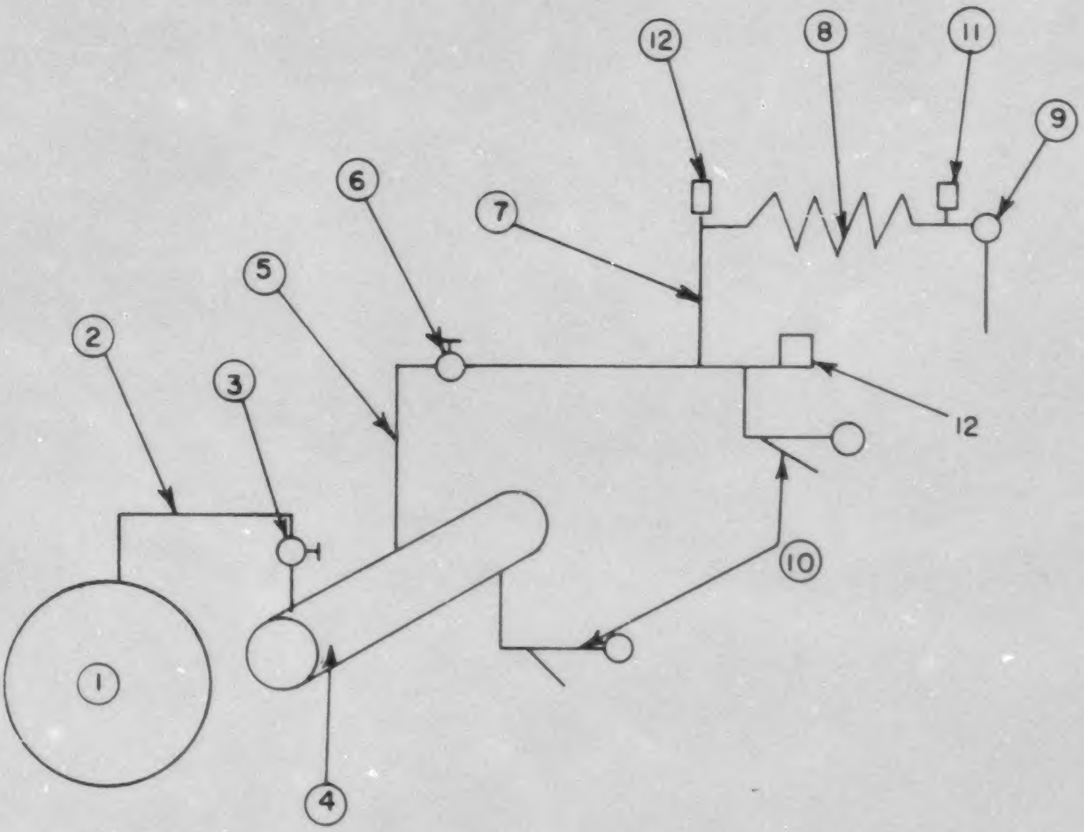
The steam must pass from the boiler (1), to the main steam line (2), through the main boiler stop valve (3), to the main header (4). From the main header it goes to the main branch lines (5), through the main branch shut-off valves (6), to the risers(7). Here the steam is led to heater (8), where it gives up its heat, condenses back to water, passes through traps (9) back to the return lines. Air is removed from the main branch lines and risers by quick vent valves (12). Air is removed from the heater by heater vent valves (11). Strainers and traps (10) are also located on the main header and main branch lines to remove condensate from the lines.

Reference: Manufacturers' data sheets

Procedure: After you have studied the listed references, answer the following questions and be prepared to discuss each in class:

Assignment:

1. What is the main purpose of a steam heating system?
2. How is this purpose accomplished?
3. What happens to steam as it gives up its heat?
4. What is condensate?
5. Why must condensate be returned to the boiler?



12
8
11
9
6
7
5
2
3
12
10
1
4

STEAM PRESSURE SYSTEM

Fig. V-A-1-1

Pressure and Vacuum Heating Systems — Assignment V-A-2

Objective: Upon completion of this lesson, the student will know the difference between pressure and vacuum heating systems.

Information: From our previous lesson we learned that the basic function of any steam heating system is to convert chemical energy into heat energy. Heat energy in the form of steam must be delivered through a system of pipes to its work area where it gives up its heat and turns back to water. This water known as condensate must be returned, again through a system of pipes called return lines, back to the boiler.

The difference between a steam pressure system and a steam vacuum system is the vent valves. In a vacuum system there are no vent valves.

Let us see how a pressure system works. First - the boiler should have better than half a gage glass of water. The rest of the system lines and heaters will be full of air.

Second: As heat is applied to the boiler, it will slowly start to build up steam pressure. As the steam leaves the boiler it will start to fill the steam lines.

Vents (sometimes referred to as quick vents) which should be located at the ends of the mains will allow the air to escape ahead of the steam. The steam traveling up the risers will start to fill the heating units.

These heating units will also be equipped with vent valves which remain open allowing the air to escape. They remain open until there is about ½ to 3/4 pounds of steam in the unit, at which time they close. If a heater vent valve is defective and air cannot escape, the heater will become air bound; no steam can enter and the unit will remain cold.

Heaters should be equipped with adjustable vent valves so that units farthest from the boiler will be set with largest air discharge openings to relieve air more quickly. Those closest to the boiler will have smaller air discharge openings. In this way heaters will warm up at about the same rate.

A vacuum system is a closed system – no air can enter. This enables the steam to enter the heating units faster, under a slight vacuum.

Reference: Manufacturers' data sheets and catalogs

Procedure: After you have studied the listed references, answer the following questions and be prepared to discuss each in class:

Assignment:

1. How is chemical energy in fuel converted to energy?
2. What is the basic difference between a pressure and a vacuum heating system?
3. How is the air removed from steam mains and heating units in a pressure system?
4. If you had a room at the end of a building that was not heating fast enough, what would you do to correct this condition? Explain in detail.

Basic Hot Water Heating System — Assignment V-B-1

Objective: Upon completion of this lesson, the student will know how a basic hot water heating system works.

Information: The basic purpose of any hot water heating system is to change the chemical energy in the fuel to heat energy in the hot water. When water gives up its heat in a heating unit, it is giving up some of its sensible heat. Sensible heat is heat that will change a substance's temperature but not its state. The water then must return to the boiler to be reheated.

It is important to note that steam radiators can be 1.6 times smaller than hot water radiators because each pound of water conveys only about 1/5 times the amount of heat that 1 pound of steam can convey. It is therefore necessary to circulate 50 times more water (by weight) than steam to produce the same amount of heat.

Hot water systems are designed to operate at about 180° F compared to 212° F for steam – again proving the need for corresponding greater hot water radiator surfaces. In a steam system, the only water is found in the boiler and the return lines. In a hot water system, all lines are filled with water.

Reference: Manufacturers' data sheets and catalogs.

Procedure: After you have read the listed references, answer the following questions and be prepared to discuss each:

Assignment:

1. How does the hot water system differ from a steam system?
2. Explain which system needs the larger radiators.
3. What medium is used to carry the heat energy in the system we have just discussed?
4. What is the usual operating temperature of a hot water heating system?

Natural Circulation Hot Water System — Assignment V-B-2

Objective: Upon completion of this lesson, the student will know how a natural (or gravity) hot water circulation heating system works.

Information: Natural or gravity hot water heating systems have been in use for many years. The use of circulating pumps was introduced to the system in the early 1930's.

Let us first look at the natural (gravity) system. In a natural circulation system, the circulation of hot water is caused entirely by the difference in density (weight per unit volume) of the water flowing to the heaters and the cooler water returning to the boiler. Water when heated expands so a gallon of hot water will have less weight than a gallon of cold water.

Check this in the following sketch. Water is heated in the boiler (1). It expands and becomes lighter in weight and flows us through the supply line (2). The water in the heaters (3) being cooler and therefore heavier, will flow down through the return line (4) to the boiler. We now have created a simple natural or gravity system circulation.

At this time we should mention the expansion tank (5). It is located at the highest point in the system, vented to the atmosphere and contains mostly air. When the water in the system is heated, it expands and increases in volume (occupies more space). The expanded water goes into the expansion tank. The expansion tank is needed to protect the system.

If a system holds 25 gallons of water at 70° F, this water would expand to about 25.5 gallons when heated to 140° F. Unless there is some way to take care of this expansion, the system could burst.

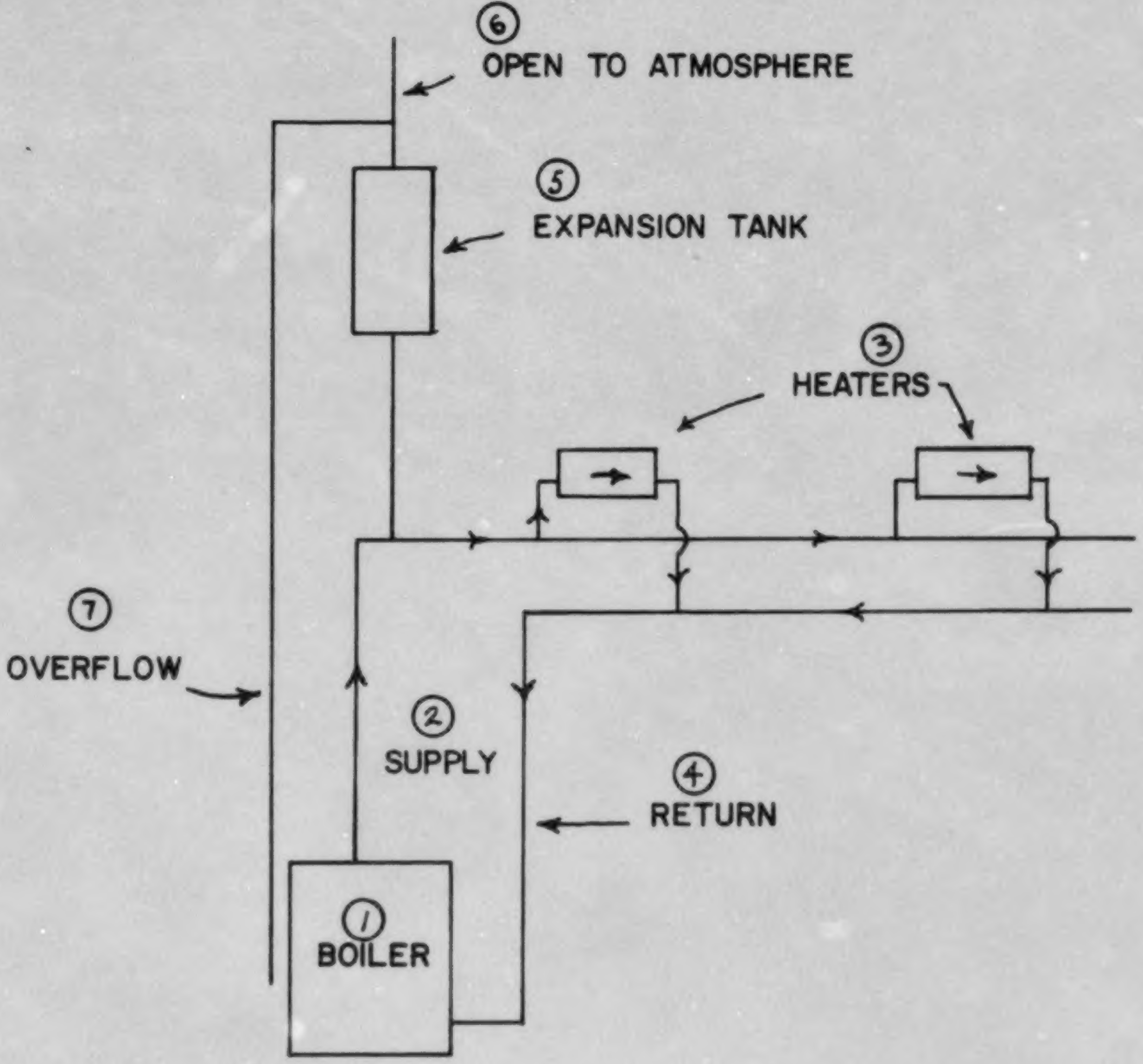
The natural circulation system worked quite well. Its big drawback is the rather small motive force; and in order not to restrict circulation, it is necessary to install large piping which is more expensive.

Reference: Manufacturers' data sheets and catalogs

Procedure: After you have read the listed references, answer the following questions and be prepared to discuss each in class:

Assignment:

1. What causes the circulation in a natural or gravity hot water heating system?
2. List the three effects of heating water.
3. Where is the expansion tank located and what purpose does it serve?
4. Do you think it would be possible to have a natural circulation system without an expansion tank? Explain.


⑥
OPEN TO ATMOSPHERE
⑤
EXPANSION TANK
③
HEATERS
⑦
OVERFLOW
②
SUPPLY
④
RETURN
①
BOILER

NATURAL CIRCULATION
HOT WATER SYSTEM

Fig. V-B-2-1

Forced Circulation Hot Water System — Assignment V-B-3

Objective: Upon completion of this lesson, the student will know how a forced circulation hot water heating system works.

Information: Hot water heat has the advantage of providing steadier heat than steam. It does cost more to install, but it could hold the cost of fuel from 10 to 15% lower than a steam system. However, it is difficult to heat long low buildings because of the low velocity in the natural circulation system. Then circulating pumps were added to the system. With the forced circulation hot water system, all the objections to the natural circulation system were overcome. It was possible to reduce heater and pipe sizes. The increased circulation made possible an almost instant supply of hot water to the heaters when needed. Let us look at a forced hot water system.

Basic Equipment

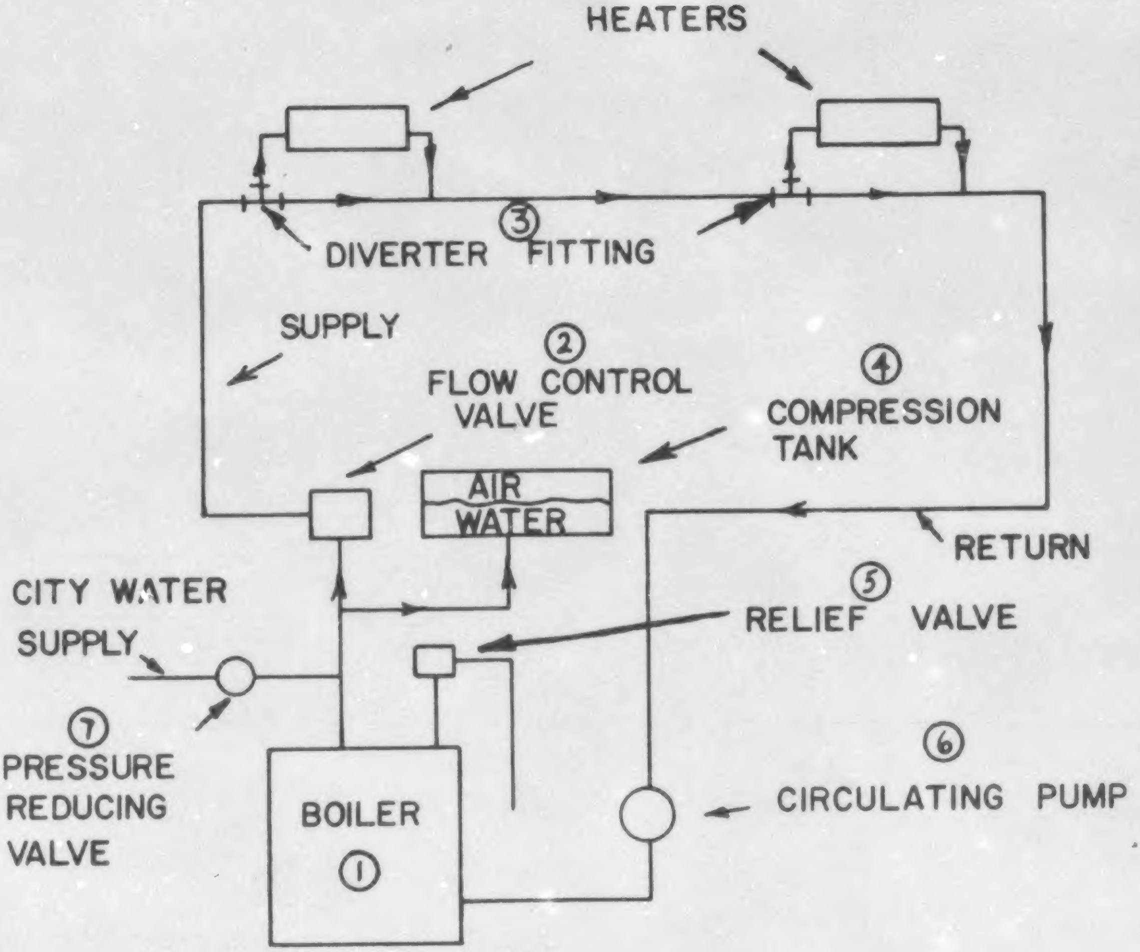
1. Boiler – serves the same purpose as in a natural circulation system.
2. Flow control valve – opens when the circulating pump runs, and closes when the pump stops. This prevents circulation of water to the heater due to natural circulation.
3. Diverter fitting – "T" shaped fitting which is carefully designed to cause enough resistance to ensure the right amount of hot water getting to heater.
4. Compression tank – tank that provides for the expansion of the heated water. Air is also compressed to provide a cushion and protect the boiler from water hammer and sudden pressure shocks.
5. Relief valve – safety device set to open if pressure in system goes over 30 p.s.i.
6. Circulating pump – centrifugal pump which is electrically operated, thermostatically controlled, and circulates the heated water through the system.
7. Pressure reducing valve – found on the city water line near the boiler. Reduces city water pressure to 12 to 18 p.s.i., thus maintaining a constant pressure.

References: Manufacturers' data sheets and catalogs

Procedure: After you have read the listed references, answer the following questions and be prepared to discuss each in class:

Assignment:

1. Why was it necessary to add a circulating pump to the basic hot wate system?
2. What purpose does the flow control valve serve?
   Why isn't there a flow control valve in a natural circulation system?
3. What is the purpose of the relief valve? What serves as a relief valve ir a natural circulation system?
4. Why can smaller size heaters and pipes be used in a forced circulation system?
5. Which of the two systems that you have just studied can operate at a higher temperature? Explain why.


HEATERS
③ DIVERTER FITTING
SUPPLY
② FLOW CONTROL VALVE
④ COMPRESSION TANK
AIR
WATER
RETURN
CITY WATER SUPPLY
⑤ RELIEF VALVE
⑦ PRESSURE REDUCING VALVE
⑥ CIRCULATING PUMP
BOILER
①

FORCED CIRCULATION
HOT WATER SYSTEM

Fig. V-B-3-1

Objective: Upon completion of this lesson, the student will know how a basic warm air heating system works.

Information: In a warm air heating system the medium used to transmit the heat to where it is needed is air. In the steam heating system, the medium used is steam; and in the water system, it is water. The air is brought from the room to a warm air furnace. It passes over the exterior of a combustion chamber and flue gas passages and then returned to the room. The simplest form of a warm air furnace is shown in the sketch following.

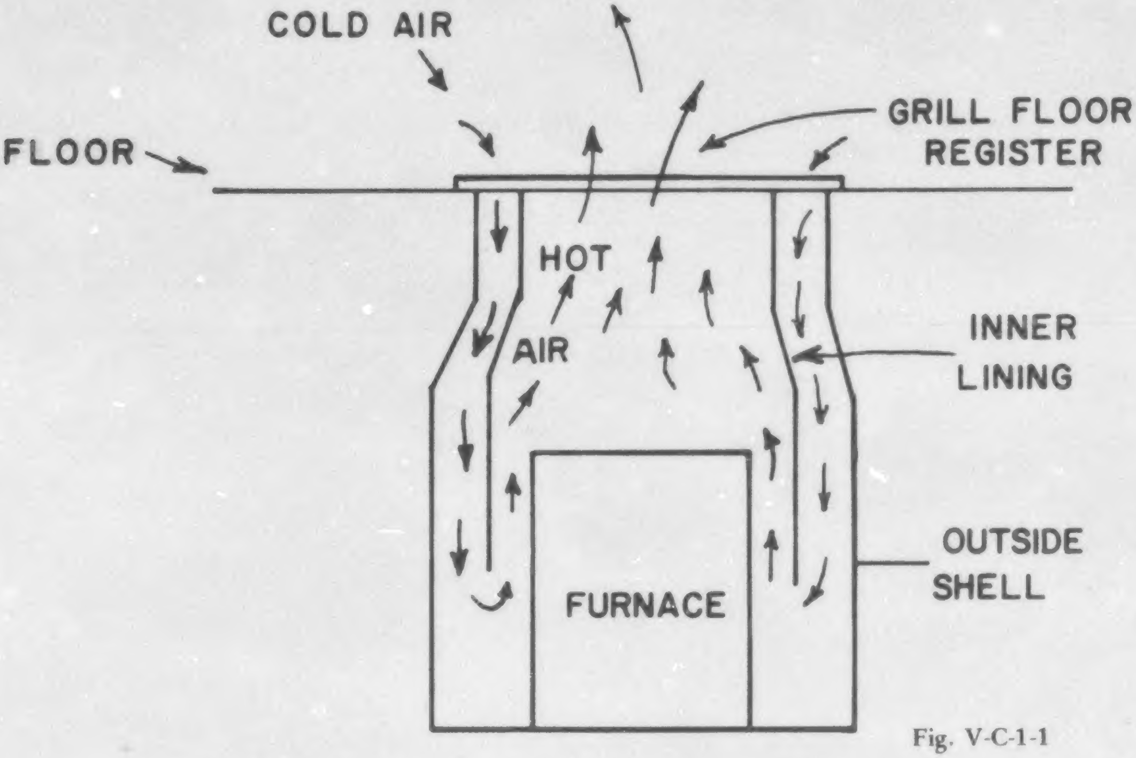


Fig. V-C-1-1

It is a pipeless system with the heat delivered only to the room directly above the furnace. Warm air moves to other rooms through open doorways and stairwells. This system is very ineffective and suitable only for small homes or buildings. The circulation again is due to natural circulation. Air when heated, much like water, expands, increases in volume, and decreases in density. This causes it to rise through the open register and the colder, more dense air to move down to the furnace to be heated. The furnace basically consists of a fire pot and a series of flue gas passes surrounded by a metal casing. The air moving through these passes absorbs the heat. The furnace is either welded steel or cast iron. It is important that all furnace joints be absolutely air tight to prevent the products of combustion from entering the room being heated. The outer casing is made of brick, galvanized steel, or aluminum.

Reference: Manufacturers' data sheets and catalogs

Procedure: After you have read the listed references, answer the following questions and be prepared to discuss each:

Assignment:

1. List the three mediums used to transmit heat that we have studied so far.
2. What happens to air when it is heated?
3. Can you give an example of natural circulation of air in nature?
4. Do you feel the system you just studied was a very effective way to heat a house? Explain.
5. What is the danger of allowing the products of combustion from getting into the room being heated?
6. What precautions are taken to eliminate this danger?

Natural Circulation Warm Air Heating System — Assignment V-C-2

Objective: Upon completion of this lesson, the student will know how a natural circulation warm air heating system works.

Information: The difference in the density of air is the force that produces circulation in a natural or gravity warm air system. The system must be carefully designed to allow circulation to take place because this force is very small.

The furnace as in all heating systems is the starting point for the heating system. Here the air is heated, expands, and drops in density. This causes it to rise and pass through leaders to the risers which carry it up to the rooms being heated.

The cooler, denser air returns to the furnace through return ducts to be reheated. The return air may all come from within the house or some can be introduced from the outside. As in a natural circulation hot water system, the air ducts must be large because of the small forces involved.

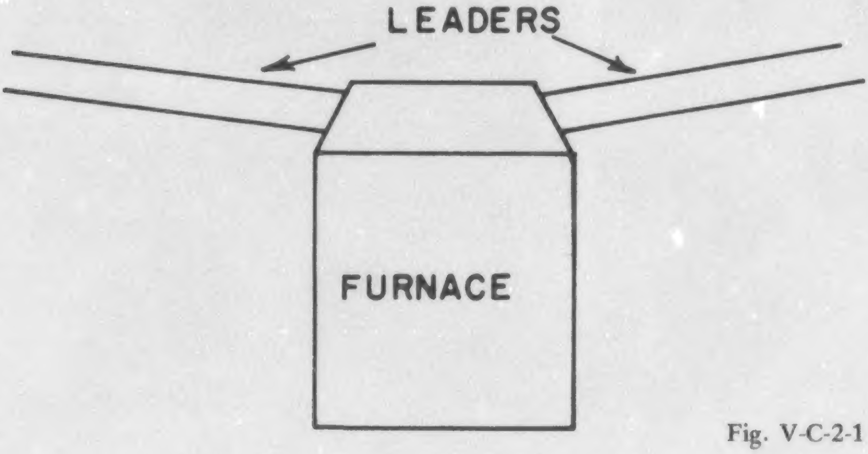


Fig. V-C-2-1

The horizontal ducts are called leaders and the vertical ducts are called stacks or risers. Horizontal ducts (leaders) should leave the furnace at the same elevation and should be pitched about 1 inch per foot.

Reference: Manufacturers' data sheets and catalogs

Procedure: After you have read the listed references, answer the following questions and be prepared to discuss each in class:

Assignment:

1. Why is design so important in a natural circulation warm air system?
2. What causes the air to circulate in a warm air system of this type?
3. What is another name for horizontal and vertical ducts?
4. Why is it important to have the horizontal ducts leave the furnace at the same elevation?
5. What causes the cooler air to return to the furnace?

Forced Circulation Warm Air Heating System — Assignment V-C-3

Objective: Upon completion of this lesson, the student will know how a forced circulation warm air heating system works.

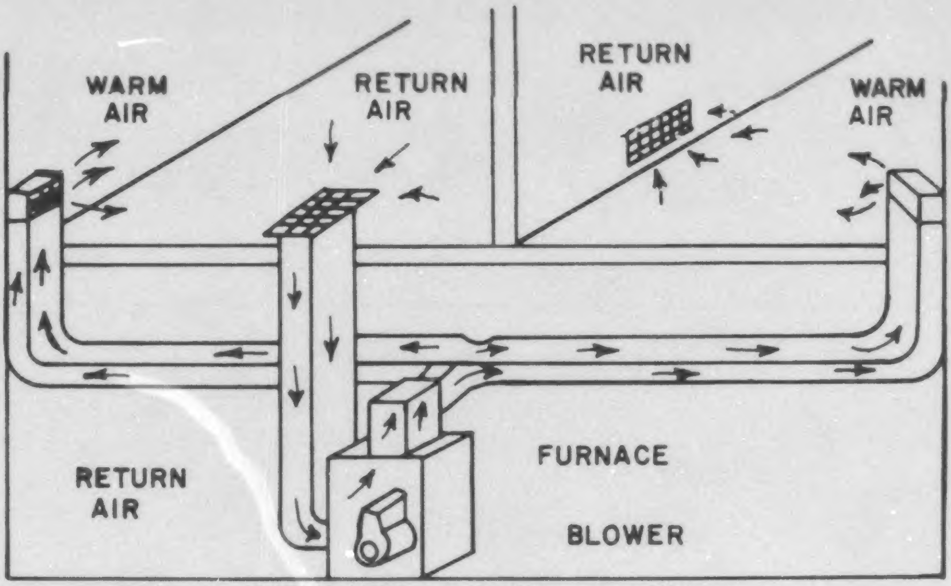
Information: From previous lessons we learned that with natural circulation, the motive force causing circulation was very small. This is true in a natural circulation warm air system as well as in a natural circulation hot water heating system. To speed up or increase this flow or force in a hot water heating system a circulating pump is added. In a forced warm air heating system, a blower is used. Look at the sketch of a forced warm air circulation system. What makes it work? A properly designed blower produces a motive force which overcomes the major difficulty of the warm air system. It also makes it possible to remove dirt, dust, and pollen by introducing filters into the system. In cold weather the heat loss is almost continuous. In a properly designed system, the heat will be supplied to each room at the same rate as the heat lost. The furnace should be adjusted so that it will operate continously or at least close to it.

Reference: Manufacturers' data sheet and catalogs

Procedure: After you have read the listed reference, answer the following questions and be prepared to discuss each:

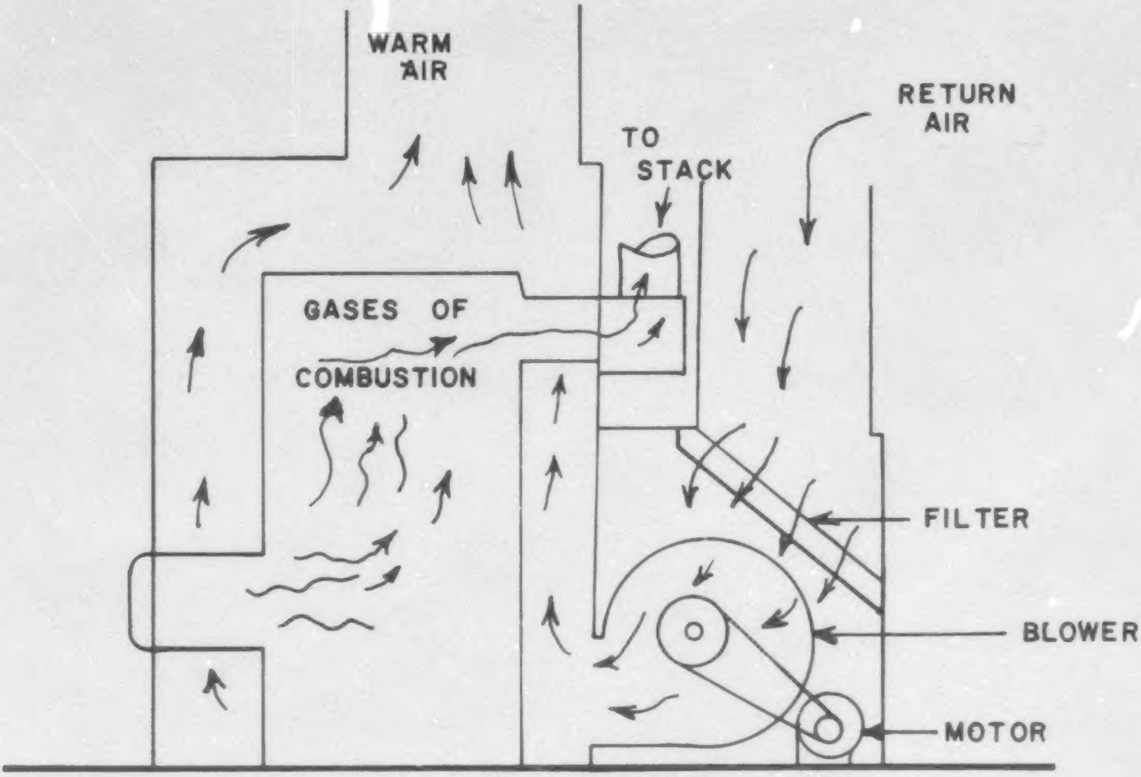
Assignment:

1. What purpose does the blower serve?
2. What purpose do the filters serve?
3. Why can't filters be used in a natural circulation warm air system?
4. Why should the furnace operate as nearly continuous as possible?


WARM AIR
RETURN AIR
RETURN AIR
WARM AIR
FURNACE
RETURN AIR
BLOWER

WARM AIR SYSTEM SHOWING SUPPLY AND RETURN DUCTS

Fig. V-C-3-1


WARM AIR
RETURN AIR
TO STACK
GASES OF COMBUSTION
FILTER
BLOWER
MOTOR

WARM AIR FURNACE SHOWING FILTER

Fig. V-C-3-2

Firetube Boilers — Assignment VI-A-1

Objectives: Upon completion of this lesson, the student will:

1. Know what firetube boilers are.
2. Be able to identify the various types of firetube boilers.

Information: All firetube boilers have the gases and heat of combustion passing through tubes that are surrounded by water. They may be classified as follows:

1. Externally fired
    a. H.R.T.
2. Internally fired
    a. Locomotive
    b. Scotch marine type

They are used for low pressure heating maximum 15 p.s.i.g., and in process plants up to about 250 p.s.i.g. where steam demands are rather small. They must be constructed in accordance to the A.S.M.E. boiler code.

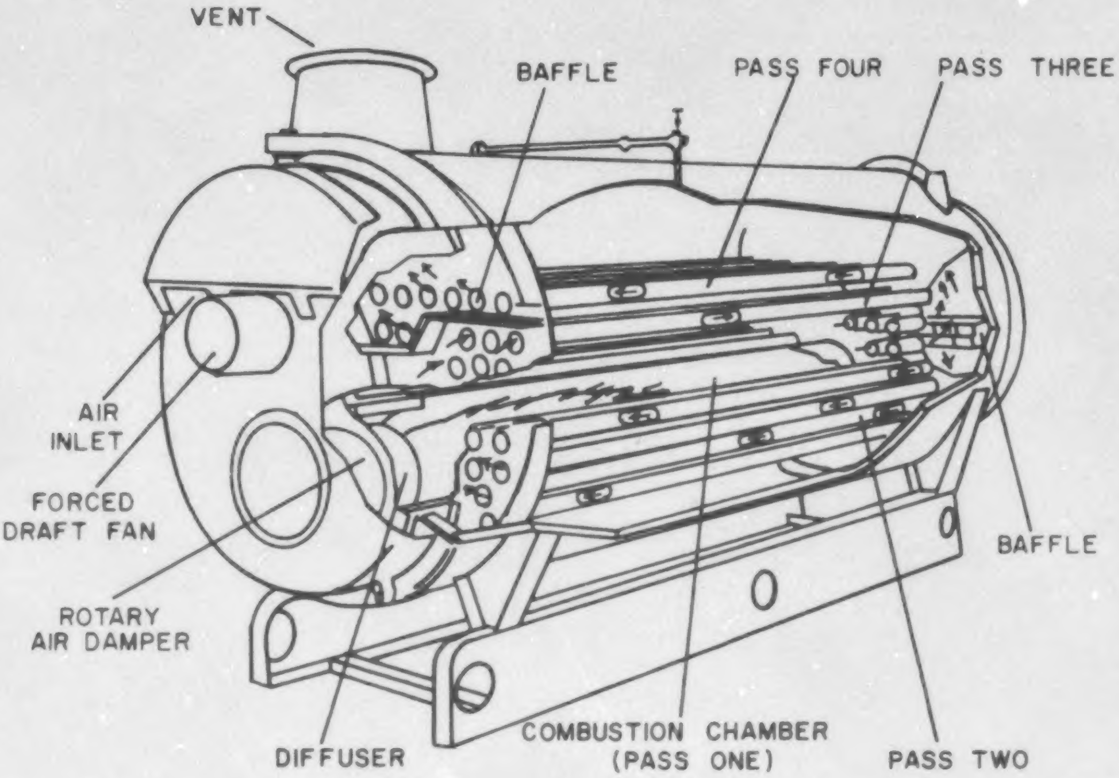
Reference:

1. *Low Pressure Boilers*
2. *Boiler Room Questons and Answers*
3. *Steam Plant Operation*

Procedure: After you have read the listed references, answer the following questions and be prepared to discuss each:

Assignment:

1. What is meant by externally and internally fired?
2. Why are firetube boilers limited to plants with relatively small steam demands?
3. What is a firetube boiler?
4. Where are firetube boilers used mainly?
5. Why do you think firetube boilers are limited to about 250 p.s.i.g?
6. List at least five types of firetube boilers.


VENT
BAFFLE
PASS FOUR
PASS THREE
AIR INLET
FORCED DRAFT FAN
ROTARY AIR DAMPER
BAFFLE
DIFFUSER
COMBUSTION CHAMBER (PASS ONE)
PASS TWO

FIRE TUBE BOILER

Fig. VI-A-1-1

Objectives: Upon completion of this lesson, the student will:

1. Know what a watertube boiler is.
2. Be able to identify the various types of watertube boilers.

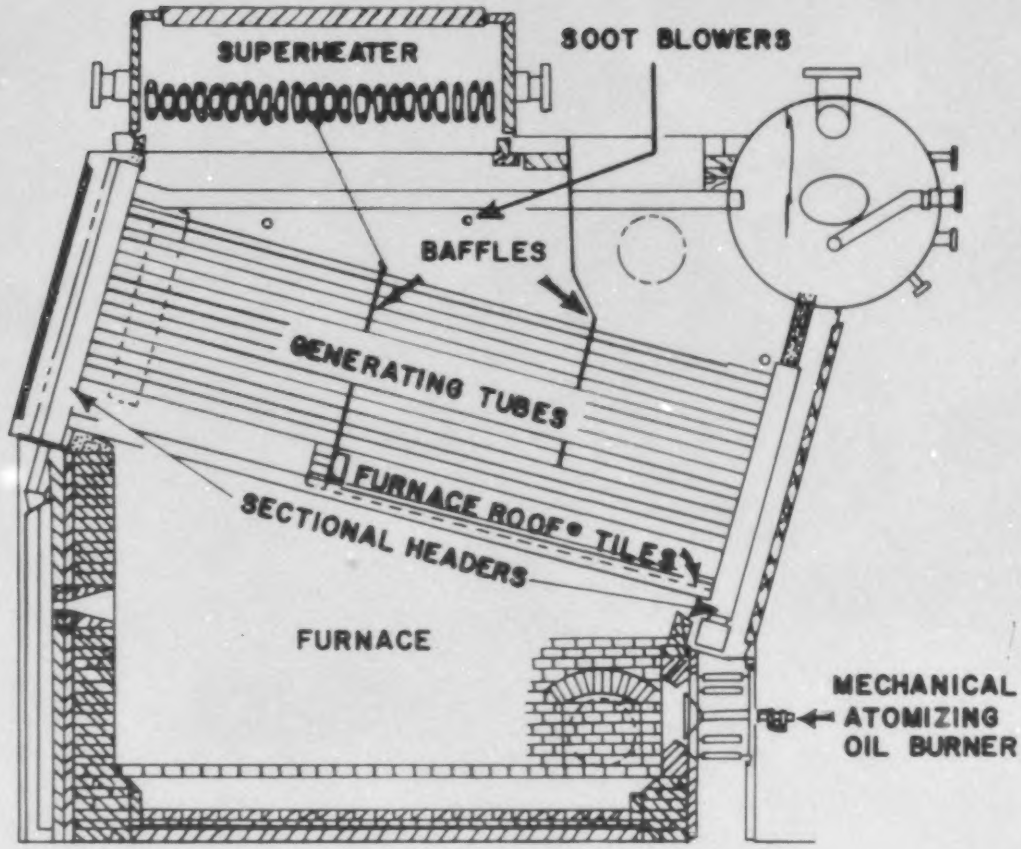
Information: All watertube boilers have water passing through tubes that are surrounded by the heat and gases of combustion. There are many models and designs of watertube boilers. They may be single- or multi-drum, straight tube or bent tube, and single pass or multipass. The watertube boiler was developed when the requirements for higher steam pressures and larger steam capacities increased in industry. The firetube boiler needed such large diameters and plate thickness to meet these demands that they were no longer practical or safe.

Reference: *Low Pressure Boilers*

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each:

Assignment:

1. What is a watertube boiler?
2. How does it differ from a firetube boiler?
3. When would you choose a watertube boiler over a firetube boiler?
4. Are watertube boilers internally or externally fired?
5. Why are watertube boilers faster steamers than firetube boilers?


SUPERHEATER
SOOT BLOWERS
BAFFLES
GENERATING TUBES
FURNACE ROOF TILES
SECTIONAL HEADERS
FURNACE
MECHANICAL
ATOMIZING
OIL BURNER

BABCOCK & WILCOX TWO INCH TUBE, SECTIONAL HEADER, THREE – PASS, MARINE BOILER

Fig. VI-A-2-1

Cast-Iron Sectional Boilers — Assignment VI-A-3

Objective: Upon completion of this lesson, the student will be familiar with a cast-iron sectional boiler.

Information: Cast-iron sectional boilers are sometimes referred to as watertube cast iron boilers. They do not have tubes. They have cast iron sections which are joined together to form a boiler. The water passes through these sections and the heat and gases of combustion surround them. They are used in low pressure heating plants (maximum pressure 15 p.s.i.g.). If they are used to heat a small building, they may have four or five sections. To heat a larger building they can have ten, twelve, or more sections. If you have ever seen a cast iron radiator you would have noticed that a small room has a small three or four section radiator. A large room may have a twelve-section radiator because it needs more heat. Can you see the comparison?

Reference:

1. *Low Pressure Boilers*
2. Manufacturers' data sheets and catalogs

Procedure: After you have studied the listed references, answer the following questions and be prepared to discuss each:

Assignment:

1. What is a cast-iron sectional boiler?
2. What is the type of service it is used for?
3. What is the maximum pressure it is capable of carrying?
4. Why are they made with different numbers of sections?

CAST - IRON
SECTIONAL BOILER

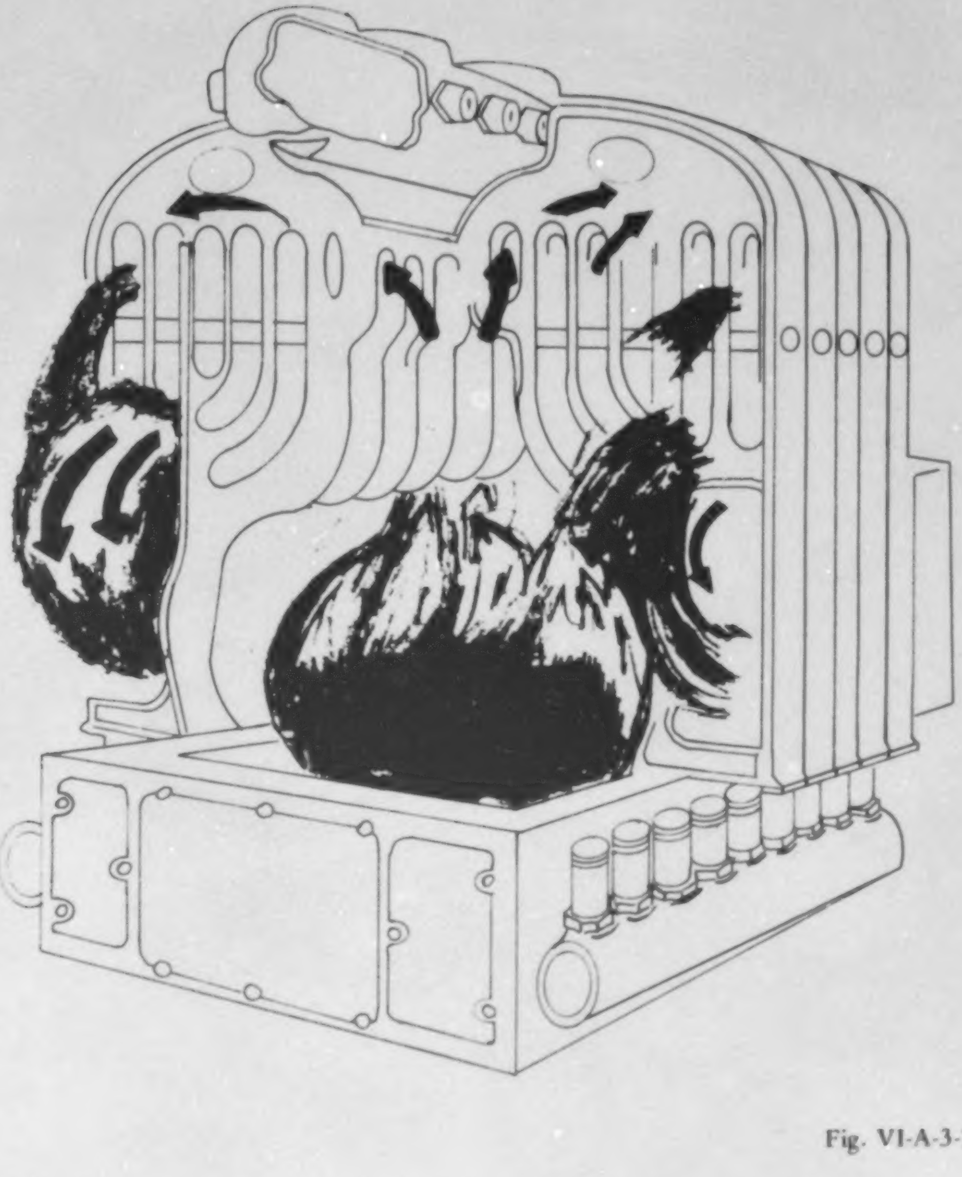


Fig. VI-A-3-1

Objective: Upon completion of this lesson, the student will be familiar with the necessary trim needed to operate a steam boiler.

Information: There is no chrome trim on a boiler. Everything found on a boiler is there for a definite positive reason. It's there for safety, efficiency, or a combination of safety and efficiency. Listen to the name and it will almost always tell you what purpose it serves. For example, a feed water regulator – now just what do you think this piece of equipment does?

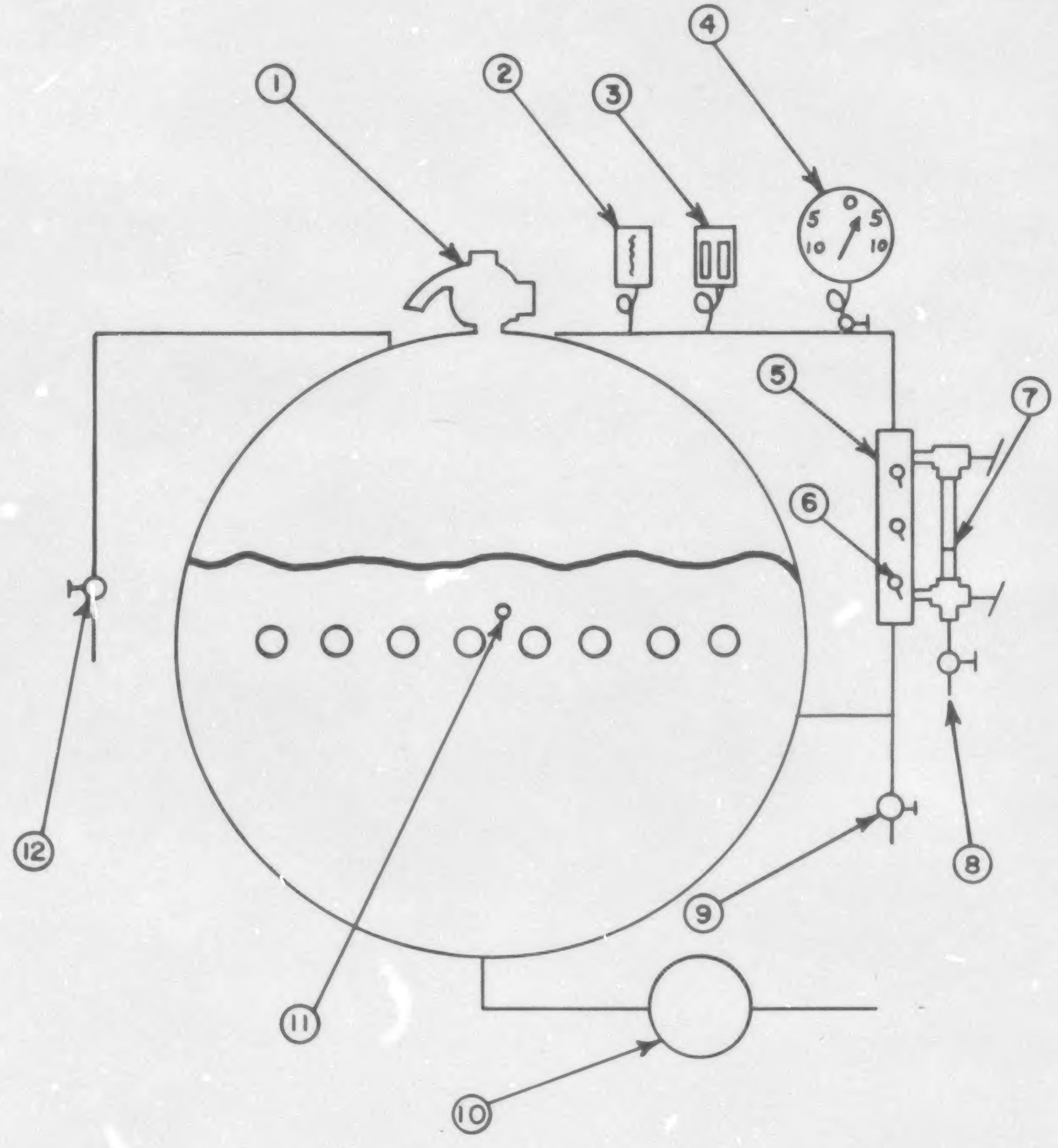
Reference:

1. *Low Pressure Boilers*
2. *Boiler Room Questions and Answers*

Procedure: After you have studied the listed references, answer the following questions and be prepared to discuss each.

Assignment: Explain the purpose and location on the sketch VI-B-1-1 of each of the following.

1. Safety valve
2. Pressure-trols
3. Modulating pressure-troll
4. Pressure gage
5. Water column
6. Try-cocks
7. Gage glass
8. Gage glass blow down
9. Water column blow down
10. Bottom blow-down valves
11. Fusible plug
12. Air cocks


4
1
2
3
0
5
5
10
10
5
7
6
12
8
9
11
10

TRIM STEAM BOILER

Fig. VI-B-1-1

Hot Water Boiler Trim — Assignment VI-B-2

Objective: Upon completion of this lesson, the student will be familiar with the necessary trim needed to operate a hot water boiler.

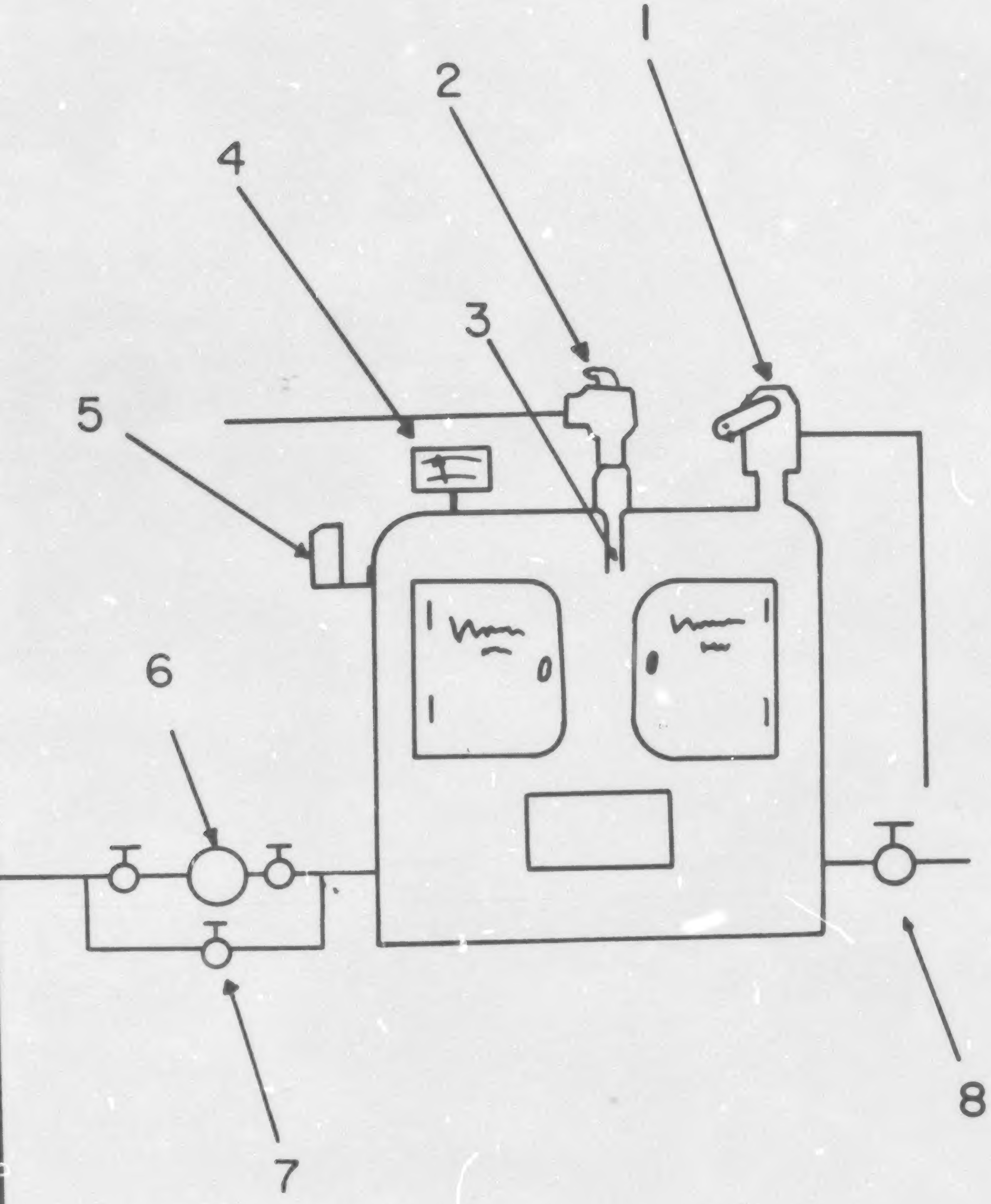
Information: Hot water boilers are usually low-pressure boilers. There are some instances where high-temperature, high-pressure hot water boilers are used for central heating in large complexes. At this time, we will confine our studies to low-pressure, hot water boilers. During the manufacturing, two boilers will be built side by side and stamped maximum allowable working pressure 15 p.s.i. steam, 30 p.s.i. water. Then when the boilers reach the end of the line one will be equipped with steam trim – the other, water trim; and that will be the only difference. From our last lesson we learned about steam trim. Now let us see what water trim is all about.

References: Manufacturers' data sheets and catalogs

Procedure: After you have studied the listed references, answer the following questions and be prepared to discuss each:

Assignment: Explain the purpose and location of the following:

1. Relief valve
2. Flow control
3. Air-trol fitting
4. Temperature-pressure gage
5. Aquastat
6. Pressure-reducing valve (city water)
7. Bypass reducing valve
8. Circulating pump



TRIM HOT WATER
BOILER

Fig. VI-B-2-1

Objective: Upon completion of this lesson, the student will be familiar with the steam accessories and know what they are used for.

Information: Steam in a boiler is of no use to us at all. We must lead it to where it does its work. In a heating system, this work consists of giving up its heat in some type of heater, which in turn heats a room. We must have full control of this steam at all times. Let us look at some of these accessories and the purpose they serve. The following sketch may help.

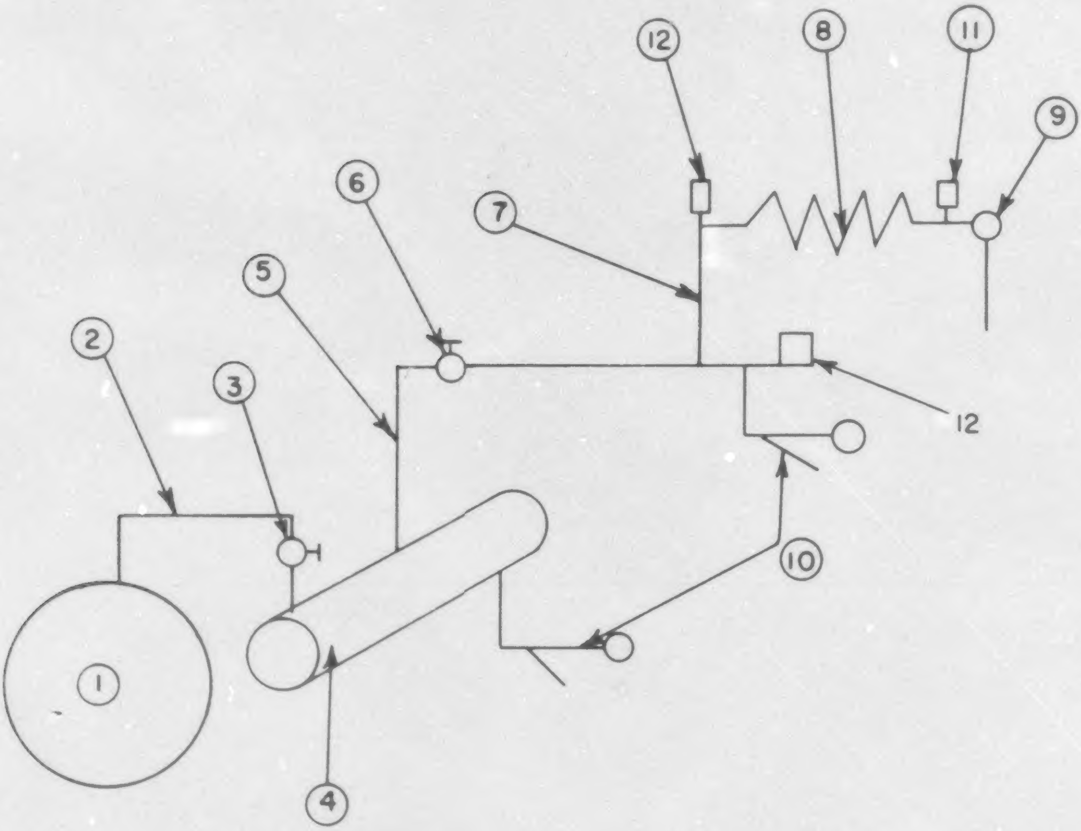


Fig. VI-C-1-1

STEAM PRESSURE SYSTEM

1. Boiler – where chemical energy of fuel is turned into heat energy of steam.
2. Main steam line – brings steam from boiler to main header.
3. Main boiler stop valve – valve which allows us to cut boiler in on line or take boiler off line (line meaning main header). Boiler stop valves are O.S. & Y gate valves (outside stem and yoke valve which shows by its position whether it is open or closed) and a gate valve because it offers no resistance to flow of steam when in open position.
4. Main header distribution panel – allows more than one boiler to be in service and distributes steam to main branch lines.
5. Main branch line – steam lines that deliver steam to different parts of the building.
6. Main branch shut-off valve – used to take steam off any section of the building to make repairs without shutting down whole system.
7. Risers – vertical steam lines coming off main branch lines bringing steam to heaters.
8. Heater – point in system where steam gives up its heat and in so doing turns back to water (condensate)
9. Trap – automatic device used to increase the over all efficiency of the plant by removing air and water from steam lines and heaters without the loss of steam.
10. Strainer and trap – when steam passes through lines some heat is lost. This causes condensation – strainers are placed before the trap to pick up any foreign matter that might cause the trap to clog and the trap removes the water. They are located at the ends of the main header and main branch lines and of course after all heaters.
11. Heater vent – if the steam system is a pressure system rather than a vacuum system, the heater must have a vent to relieve air. If the air is trapped in the heater, it would become air bound and no steam could enter.
12. Quick vents – located at the end of main branch lines and at the highest part of riser – this vents air from lines quickly when building up steam pressure in a cold system. They are not found in a vacuum system.

Reference: *Low Pressure Boilers*

Procedure: After you have studied the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. Why are main stop valves needed on a boiler?
2. What purpose does the main header serve?
3. What type of valve should be used on main headers and main steam lines? Explain why.
4. Why must there be a trap at the end of the main header and branch lines?
5. Explain what you think would happen if the traps on the main header stuck closed.
6. Why is it not necessary to use heater vents and quick vents in a vacuum system?
7. Describe how three types of traps work.

Objective: Upon completion of this lesson, the student will know where hot water accessories are located and what function they perform in a system.

Information: In order to accomplish our objective in a hot water system, we must be able to control the delivery of the proper amount of water to heaters. Not enough water would result in a cold building. The following sketch may help you to understand the purpose and location of the hot water accessories used.

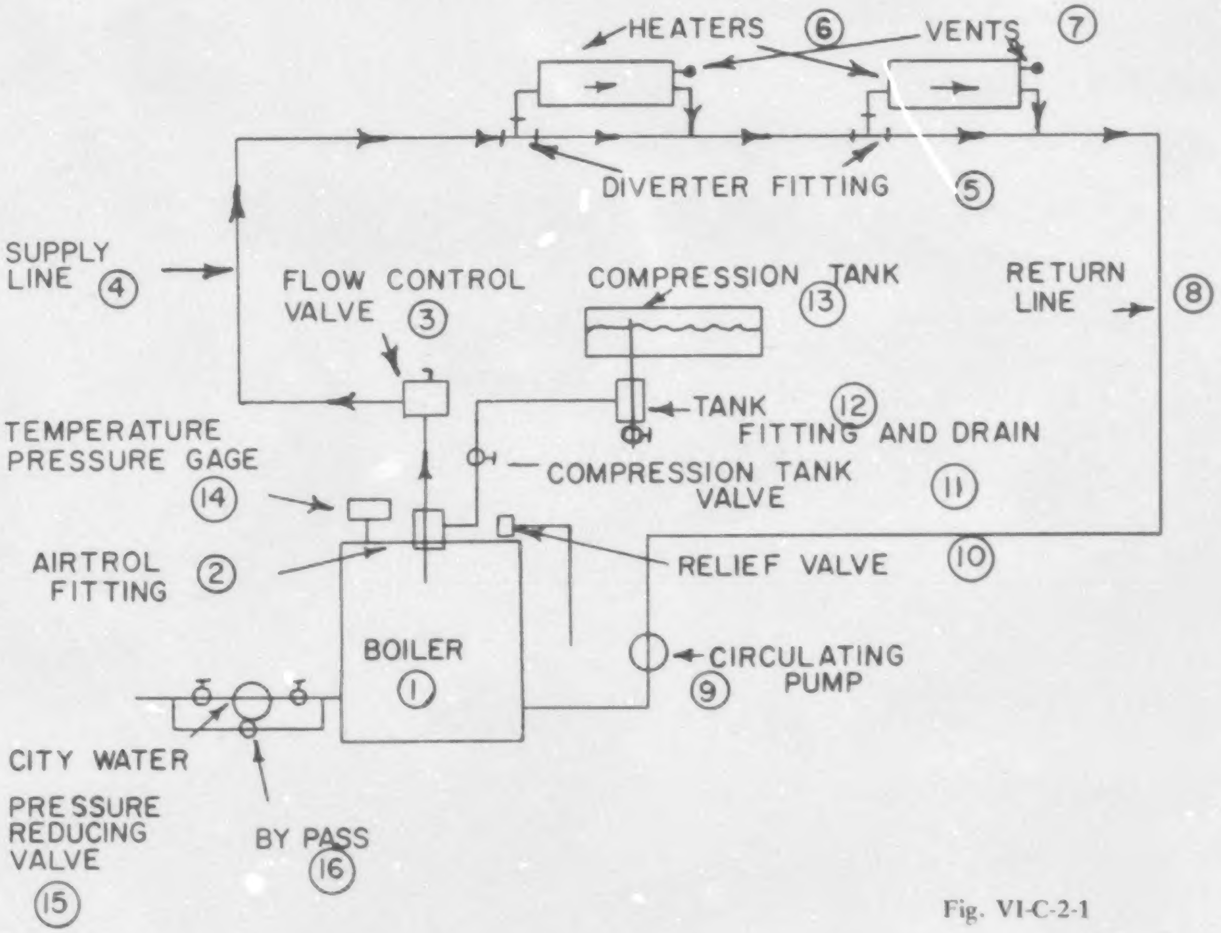

HEATERS ⑥
VENTS ⑦
DIVERTER FITTING ⑤
SUPPLY LINE ④
FLOW CONTROL VALVE ③
COMPRESSION TANK ⑬
RETURN LINE ⑧
TANK ⑫ FITTING AND DRAIN
TEMPERATURE PRESSURE GAGE ⑭
COMPRESSION TANK VALVE ⑪
AIRTROL FITTING ②
RELIEF VALVE ⑩
BOILER ①
CIRCULATING PUMP ⑨
CITY WATER
PRESSURE REDUCING VALVE ⑮
BY PASS ⑯

Fig. VI-C-2-1

1. Boiler – where water is heated.
2. Air-Trol fitting – located at top of boiler. A tee-shaped fitting with a tube that extends from the supply line down into the boiler water. It prevents the air that will accumulate at the top of the boiler from entering the supply line and heaters. The air is instead led to the compression tank (13).

3. Flow control valve -- located in supply line close to top of boiler. It will open when circulating pump (9) starts and close when the pump stops. This is necessary to prevent natural circulation which could cause an override in room temperature found only on forced hot water heating systems.

4. Supply line – piping that carries heated water to the various heaters in the system. It should always be pitched so that the air can be vented by either an open expansion tank, heater vents, or air vent valves. Care must be taken to allow for expansion and contraction during temperature changes.

5. . Diverter fitting – tee-shaped fitting located in supply main. It allows the use of a single supply line rather than a separate supply and return line. It must be carefully engineered so that it will introduce the proper resistance which will ensure the right amount of water being diverted up to the heater.

6. Heater – the point of the system where heat transfer takes place. Heaters will vary in design and material; for example:

   a. cast iron radiators

   b. cast iron convectors

   c. copper fin type convectors

   d. unit heaters (wall or ceiling)

7. Heater vents – vent valves are located at the top part of the heater and may be automatic or manual valves. They are used to rid the heater of any air that may be trapped. If this air was not removed, the heater would become air bound. This restricts or stops the circulation of water leading to a cold room.

8. Return line – piping that returns the water back to the boiler for heating. It can be a continuation of the supply line, or in some systems there will be a separate return.

9. Circulating pump – centrifugal pump thermostatically controlled that circulates the heated water through the system. This positive circulation will make possible the use of smaller supply lines and heaters.

10. Relief valve – considered a fitting rather than an accessory. It was discussed in previous lessons, but it is important enough to mention again. It is used to protect the system and boiler from rupture due to over pressure. It will open when system pressure exceeds 30 p.s.i.

11. Compression tank shut-off valve – valve for closing the feed to the compression tank. Allows tank to be drained if it becomes water logged.

12. Tank fitting and drain – used to separate air from water by sending air to top of compression tank during normal operation. It also allows air into tank when draining due to water logged condition.

13. Compression tank – located above the boiler and used in a forced circulation system. It provides a place for the heated water to expand and the air above the water to be compressed. This provides a cushion against a water hammer. It also maintains a steady pressure in the system. If the pressure is increased the boiling point of the water is increased. This will allow higher water temperatures to be carried in the system resulting in use of smaller heaters. In a natural circulation system an expansion tank was used instead of a compression tank. We discussed this in the previous lesson.

14. Temperature-pressure gage – this was mentioned when we discussed hot water trim. The temperature-pressure gage is located at the top of the boiler. It will record boiler water temperature and pressure in the system. An additional red pointer is provided for setting on the particular system. This is the normal pressure or altitude that you need to maintain for good heating. This pressure is maintained by the pressure reducing valve on the city water line.

15. Pressure-reducing valve – located on city water line. It is factory set at about 12 p.s.i. There is an adjustment on top that will enable you to increase pressure if the system requires it. There is a strainer built into the base of this valve that must be cleaned and inspected at regular intervals. The reducing valve should have two valves installed, one before it and one after and a bypass valve around it. This will enable you to work on the valve without having to dump (empty) the boiler. Usually a two-story building will require a 12 p.s.i. pressure on the system which is about 25 ft. on the altitude gage. A three-story building requires 15 p.si. pressure which is about 35 ft. on the altitude gage. It is also recommended that the highest radiation in the system have about 4 p.s.i. pressure on it at all times.

Reference: Manufacturers' catalogs and data sheets

Procedure: After having read the listed reference, answer the following questions and be prepared to discuss each.

Assignment:

1. What function does the boiler serve?
2. Why do you think it is important to use an air-trol fitting?
3. What causes the flow control valve to operate? Can this valve be used in all hot water heating systems?
4. Why are heater vents necessary?
5. How could you get some circulation in a forced circulation system if the circulating pump failed?
6. What is the maximum pressure allowed on a hot water heating system? What protects this system from over pressure?

7. What effect would a water logged compression tank have?
8. Why is it necessary to have a combination temperature-pressure gage rather than a straight pressure gage on a system of this type?
9. Why is a pressure-reducing valve needed on the city water line before it enters the boiler?

Warm Air Accessories — Assignment VI-C-3

Objectives: Upon completion of this lesson, the student will identify the location and know the purpose of the following in a warm air system:

1. Ducts
2. Filters
3. Blowers
4. Humidifiers

Information: In our previous units we studied the basic warm air heating system and its limitations.

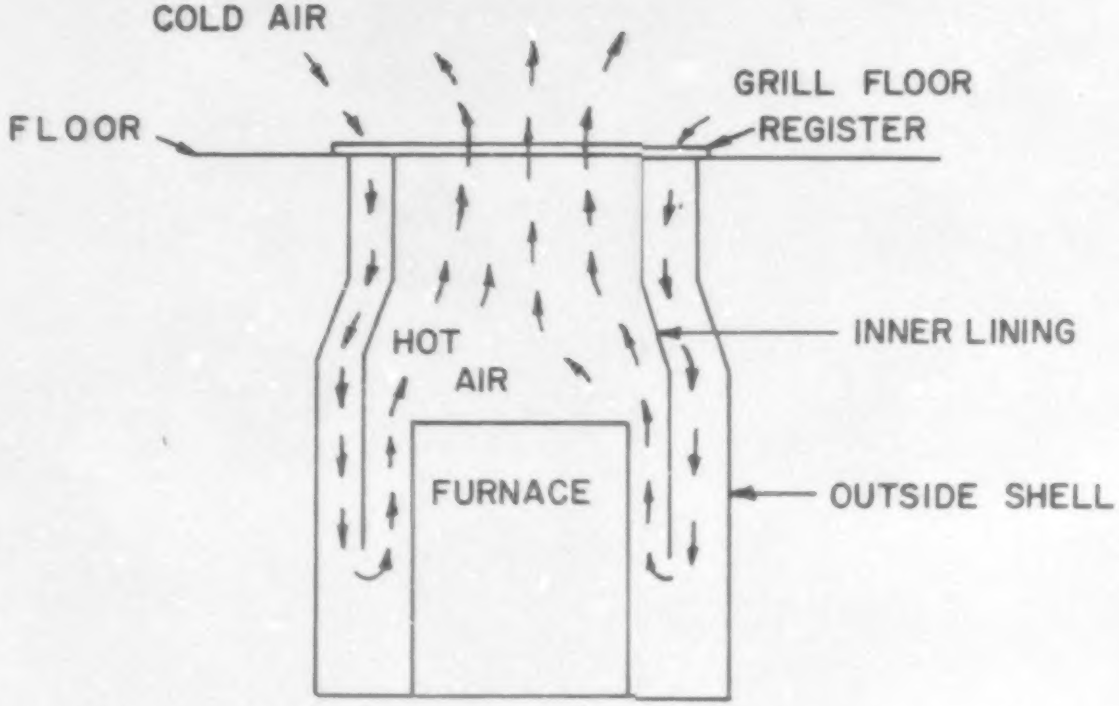
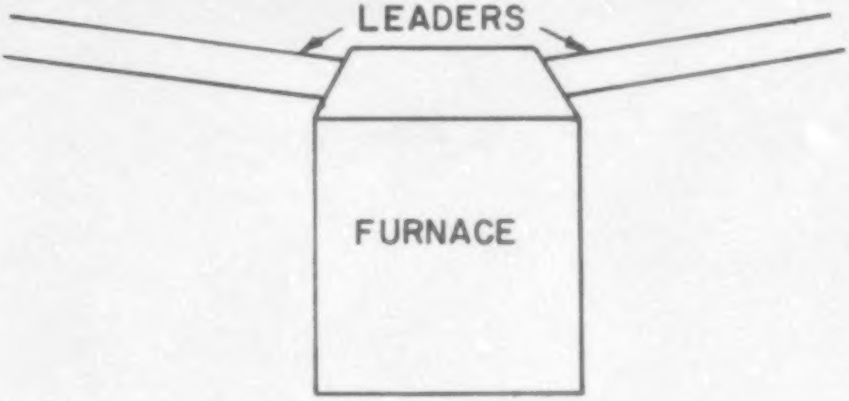
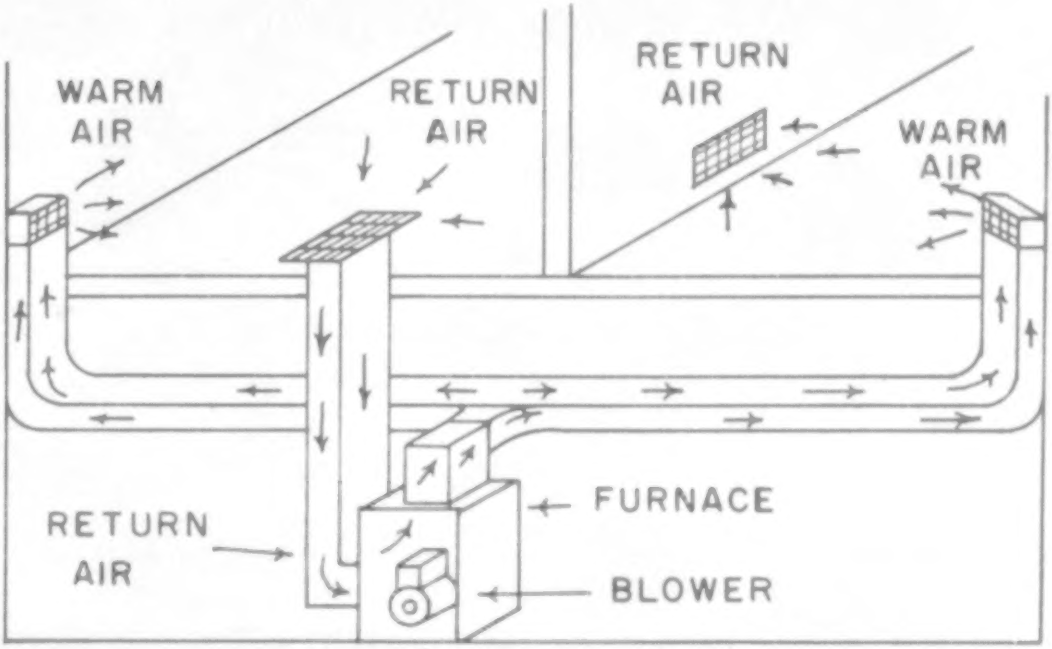

COLD AIR
GRILL FLOOR
REGISTER
FLOOR
INNER LINING
HOT
AIR
FURNACE
OUTSIDE SHELL

Fig. VI-C 3-1

Then we studied the natural circulation warm air heating system and noted its improvements.


LEADERS
FURNACE

It was still in need of refinement; and this led to the development of forced circulation warm air heating systems. The use of return ducts as well as supply ducts added to the control and flexibility of this system. By installing dampers in the ducts it enabled the heating technician to balance the heating load. This made it possible to supply just the right amount of heat wanted, taking individual personal preferences into account.


WARM AIR
RETURN AIR
RETURN AIR
WARM AIR
RETURN AIR
FURNACE
BLOWER

WARM AIR SYSTEM SHOWING SUPPLY AND RETURN DUCTS

Fig. VI-C-3-3

The filters remove dust and pollen from the air. Filters vary in cost and design. It is possible to use throwaway filters, or you can get filters that may be washed out and reused. The latest filter on the market is an electrostatic filter that claims to be very effective in removal of most foreign matter from the air. It is quite beneficial to hay fever and asthma sufferers. This drawing shows the location of the filter in the system.

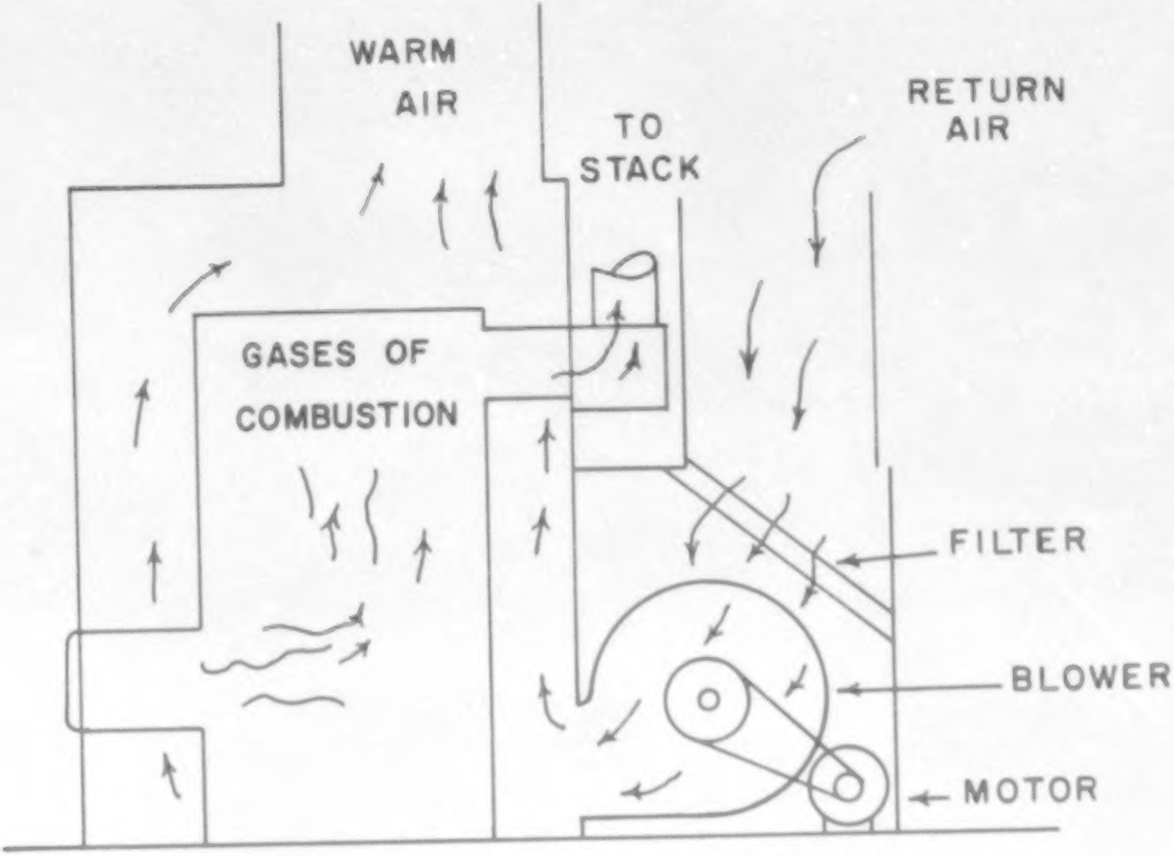


Fig. VI-C-3-4

The blower does two jobs: it pulls the return air from the rooms and pushes the heated air back into the rooms. During this process, the air is filtered and heated.

The air being supplied to the rooms becomes dry after having been heated. This dry heat is very uncomfortable and led to the introduction of humidifiers. Humidifiers vary in design but their function is similiar.

After the air is heated it passes through a humidifier, where a controlled amount of moisture is added to the air on its way to the rooms to be heated. The added moisture adds to the comfort of the living area. The humidifier has to be checked and cleaned at regular intervals. Some have float control valves, which must be maintained if you want to prevent flooded heater rooms.

Reference: Manufacturers' data sheets and catalogs

Procedure: Study the listed references, do the following assignment, and be prepared to discuss each in class.

Assignment:

1. What purpose do the return air ducts serve?
2. What do you think would happen to the heating system if the filters were not cleaned or changed?
3. Why are the blowers belt driven instead of direct drive?
4. Are the blowers high or low speed units? Explain your answer.

Objectives: Upon completion of this lesson the student will:

1. Be familiar with the theory of operation.
2. Know the purpose and location of reciprocating pumps.
3. Know the meaning of the data found on the name plate.

Information: A reciprocating pump is a positive displacement pump. You will have the opportunity in shop to thoroughly examine all its parts and learn how they work. Our purpose now is to learn the theory of operation, or why it works. How is it possible to supply 100 p.s.i. of steam to a reciprocating pump and deliver 400 p.s.i. of water at the discharge side of the pump? This can only happen by design. A reciprocating feed water pump has a steam side and a water side. The steam piston must be 2 to 2½ times larger in *area* than the water piston.

The purpose of any pump is to move a liquid from one location to another. In the case of a feed water pump it must take water usually from a feed water heater and deliver it to a boiler, at a pressure greater than the boiler pressure. If the pressure of the water was less than the boiler pressure, do you think the water would enter the boiler?

The location of a reciprocating pump will depend on the purpose it serves. It is generally found close to the source of the liquid it is to pump. Again taking a feed water pump as an example, the pump will be close to and below the tank or feed water heater. The reason for this is to give a positive suction pressure to the pump.

All reciprocating pumps have a name plate with certain numbers on it. This name plate is most important to the operating engineer. The data will tell him the size of his pump and enable him to figure out how much steam pressure is needed to obtain a certain discharge pressure. Or, he can figure the discharge pressure to be expected by knowing the amount of steam pressure on hand to drive the pump.

The name plate data might read 4 X 2 X 6. The numbers are in inches and indicate the following:

First number – diameter of the steam piston.

Second number – diameter of the water piston.

Third number – length of the stroke.

References: *Steam Plant Operation*

Elementary Steam Power Engineering

Procedure: After having studied the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Explain the theory of operation of a reciprocating feed water pump.
2. Why is it necessary to have the discharge pressure of a pump higher than the boiler pressure?
3. What does the pump name plate data, 8 X 4 X 6, mean?
4. Two reciprocating pumps have the following name plate data:
    a. 3 X 2 X 6
    b. 3 X 8 X 12

    Which would you select as a feed water pump and explain why?

Use of Force in Reciprocating Pumps

Assignment VI-D-2

Objectives: Upon completion of this lesson, the student will:

1. Understand what is meant by *total force = total force.*
2. Find the steam pressure needed by knowing the water pressure developed when using *total force = total force.*
3. Find the water pressure developed by knowing the steam pressure on hand when using *total force = total force.*

Information: What is *total force*? This term will come up all through your studies in engineering. It is a basic concept you must understand.

Total force may be defined as a sum of the forces acting in one direction. An example would be steam pressure being applied to the surface area of the head of a piston.

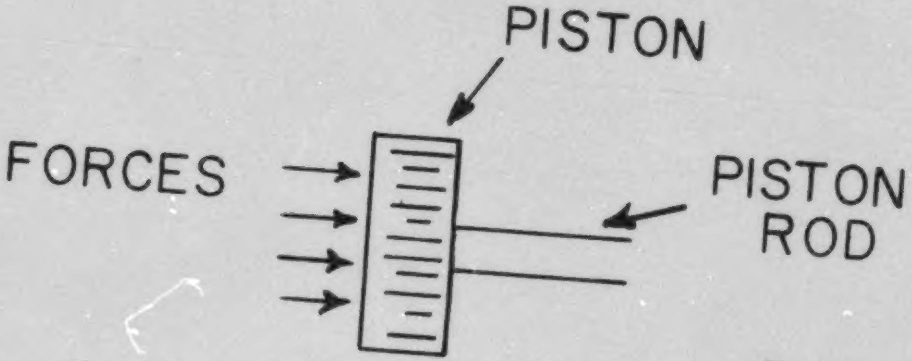


Fig. VI-D-2-1

The *total force* acting on the steam piston would then be the steam pressure × the area of the steam piston (the area being in square inches). The *total force* acting on the water piston would be the water pressure × the area of the water piston.

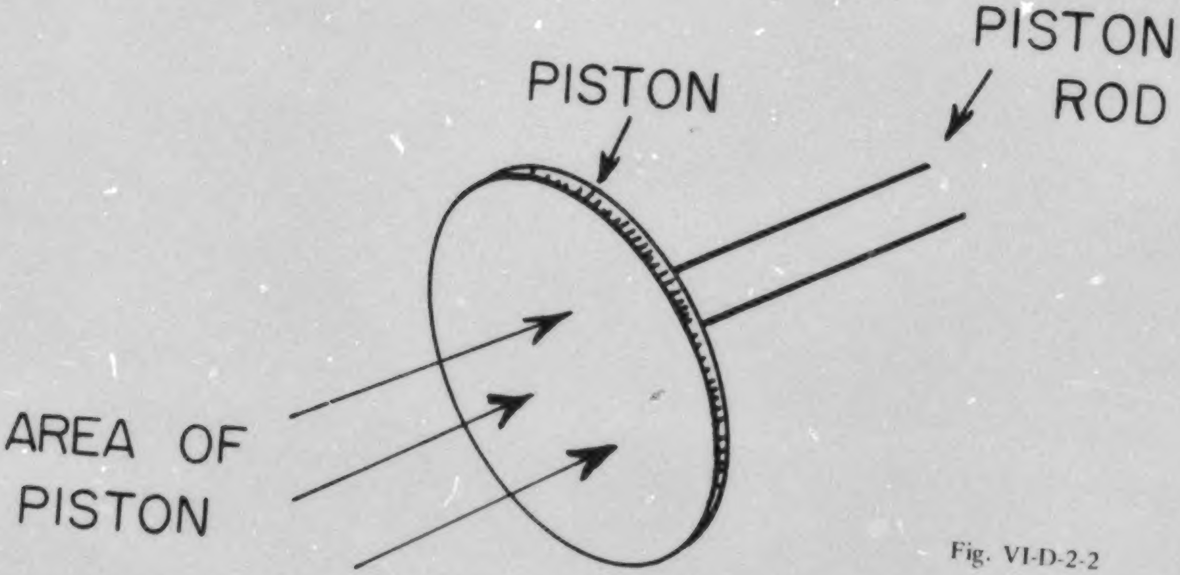


Fig. VI-D-2-2

Example: A reciprocating pump 4 X 2 X 6 is being driven with steam at 100 p.si. and develops 400 p.s.i. on the discharge side.

Total Force Steam Side = Total Force Water Side

Area Steam Side X Steam Pressure = Area Water Side X Water Pressure

The area of the piston is found by multiplying D^2 (diameter of piston squared) X .7854.

Therefore, for a 4 X 2 X 6 pump, we get:

$4^2 \times .7854 \times 100$ p.s.i. = $2^2 \times .7854 \times 400$ p.s.i.

Or, $4 \times 4 \times .7854 \times 100 = 2 \times 2 \times .7854 \times 400$

$$12.5664 \times 100 = 3.1416 \times 400$$

$$1256.6400 = 1256.6400$$

Total Force = Total Force

If you know the water pressure developed or needed you can find the steam pressure required.

Example: Pump 6 X 3 X 6 develops 600 p.s.i. on the water side. How much steam pressure is required to operate this pump?

Total Force Steam Side = Total Force Water Side

Area Steam Side X Steam Pressure = Area Water Side X Water Pressure

D^2 S.S. X .7854 X Steam Pressure = D^2 W.S. X .7854 X Water Pressure

$$\frac{\cancel{D^2\ S.S.} \times \cancel{.7854} \times \text{Steam Pressure}}{\cancel{D^2\ S.S.} \times \cancel{.7854}} = \frac{D^2\ W.S. \times \cancel{.7854} \times \text{Water Pressure}}{D^2\ S.S. \times \cancel{.7854}}$$

$$\text{Steam Pressure} = \frac{D^2\ W.S \times \text{Water Pressure}}{D^2\ S.S.}$$

$$= \frac{3 \times 3 \times 600}{6 \times 6}$$

$$= 150 \text{ p.s.i. required}$$

If you know the steam pressure available you can find the discharge pressure.

Example: Pump 6 X 3 X 6 is supplied with 150 p.s.i. steam. What pressure will be developed on the water side?

Total Force Steam Side = Total Force Water Side

Area Steam Side X Steam Pressure = Area Water Side X Water Pressure

D^2 S.S. X .7854 X Steam Pressure = D^2 W.S. X .7854 X Water Pressure

$$\frac{D^2\ S.S. \times \cancel{.7854} \times \text{Steam Pressure}}{D^2\ W.S. \times \cancel{.7854}} = \frac{\cancel{D^2\ W.S.} \times \cancel{.7854} \times \text{Water Pressure}}{\cancel{D^2\ W.S.} \times \cancel{.7854}}$$

$$\frac{D^2 \text{ S.S.} \times \text{Steam Pressure}}{D^2 \text{ W.S.}} = \text{Water Pressure}$$

$$\frac{6 \times 6 \times 150}{3 \times 3} = \text{Water Pressure}$$

$$600 \text{ p.s.i.} = \text{Water Pressure developed}$$

Procedure: After having studied the listed examples given, do the following assignment.

Assignment:

1. A reciprocating pump 4 X 2½ X 6 uses steam at 200 p.s.i. Find the pressure developed on the water side and prove your answer.
2. A reciprocating pump 5 X 3 X 8 must develop 500 p.s.i. on the discharge side. Find the steam pressure needed to run this pump and prove your answer.
3. A sales representative recommends a reciprocating pump 6 X 4 X 6 to use 250 p.s.i. steam. He also states that the pump will develop 800 p.s.i. on the discharge side. It is your responsibility to OK this purchase. Prove that he is right or wrong.

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with the theory of operation.
2. Know the purpose and location of centrifugal pumps.
3. Know the parts of a centrifugal pump.

Information: Before going into the theory of operation of a centrifugal pump we should understand some basic terminology.

- a. Centrifugal force – the inertia of a body revolved around a center tending to move it away from the center.
- b. Kinetic energy – energy due to a body in motion. An example of this is a boulder rolling down a hill.
- c. Potential energy – energy that is due to position, not to motion. An example of this is a boulder resting at the top of the hill.

Pumping is the addition of energy to a liquid to move it from one point to another. One of Mans' oldest aids, the pump, ranks second only to the electric motor as the most widely used industrial machine. A centrifugal pump enploys centrifugal force to develop a pressure rise for moving a liquid.

There are five major types of centrifugal pumps today:

- a. volute
- b. diffusar
- c. mixed-flow
- d. axial-flow
- e. turbine

These five types can be broken down into different categories such as:

- a. single-stage
- b. multistage
- c. horizontal
- d. vertical
- e. single suction
- f. double suction

In addition, to meet industries' demands there are an infinite variety of available pumps manufactured.

To better understand how a centrifugal pump works several of the parts must be defined.

a. Impeller – the rotating element in a centrifugal pump through which liquid passes and by means of which energy is imparted to the liquid.

b. Casing – the housing surrounding the impeller causing the liquid to flow from the pump in a controlled manner.

As the liquid passes into the rotating impeller, the kinetic energy overcomes the potential energy and gives it centrifugal force. Once the liquid is thrown from the impeller, the casing guides the liquid to its destination. The result is a workable pump for imparting energy to a liquid at one point which causes it to move to another point.

Anything that will flow is pumped, and the purpose of a pump is to move a liquid from one point to another under certain conditions at a specified pressure and volume. Ultimately the design of the pump depends upon its application or service.

Thus centrifugal pumps are termed:

a. boiler-feed
b. general purpose
c. sump
d. deepwell
e. condensate
f. vacuum
g. process
h. sewage
i. trash
j. booster
k. chemical
l. fire

In general each pump has specific features of design and material recommended by the builder for the particular service. This makes selection and application easier.

The following is a list of parts found on a centrifugal pump describing the function of each:

a. Upper casing – removable and directs flow of liquid from pump.

b. Impeller – the rotating element in a centrifugal pump through which liquid passes and by means of which energy is imparted to the liquid.

c. Lower casing – stationary and not removable, directs the flow of water from the pump.

d. Impeller shaft – connected at one end to a motor or steam turbine: it is used to rotate the impeller.

e. Shaft bearings – supports and allows impeller shaft to rotate.

f. Coupling – method used to attach pump shaft to motor or turbine shaft.

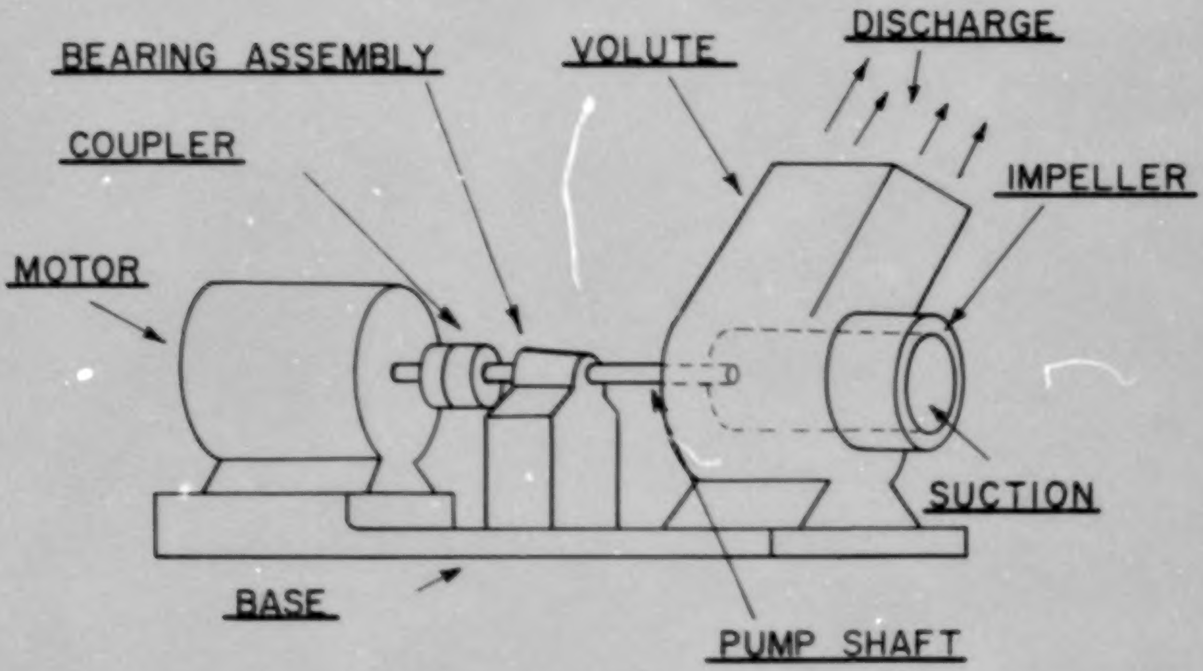
g. Packing gland – used to seal liquid into pump.

Reference: Manufacturers' data sheets and catalogs
Practical Power Service Library
Steam Plant Operation

Procedure: Study the listed references and the information given: then do the following assignment and be prepared to discuss each in class.

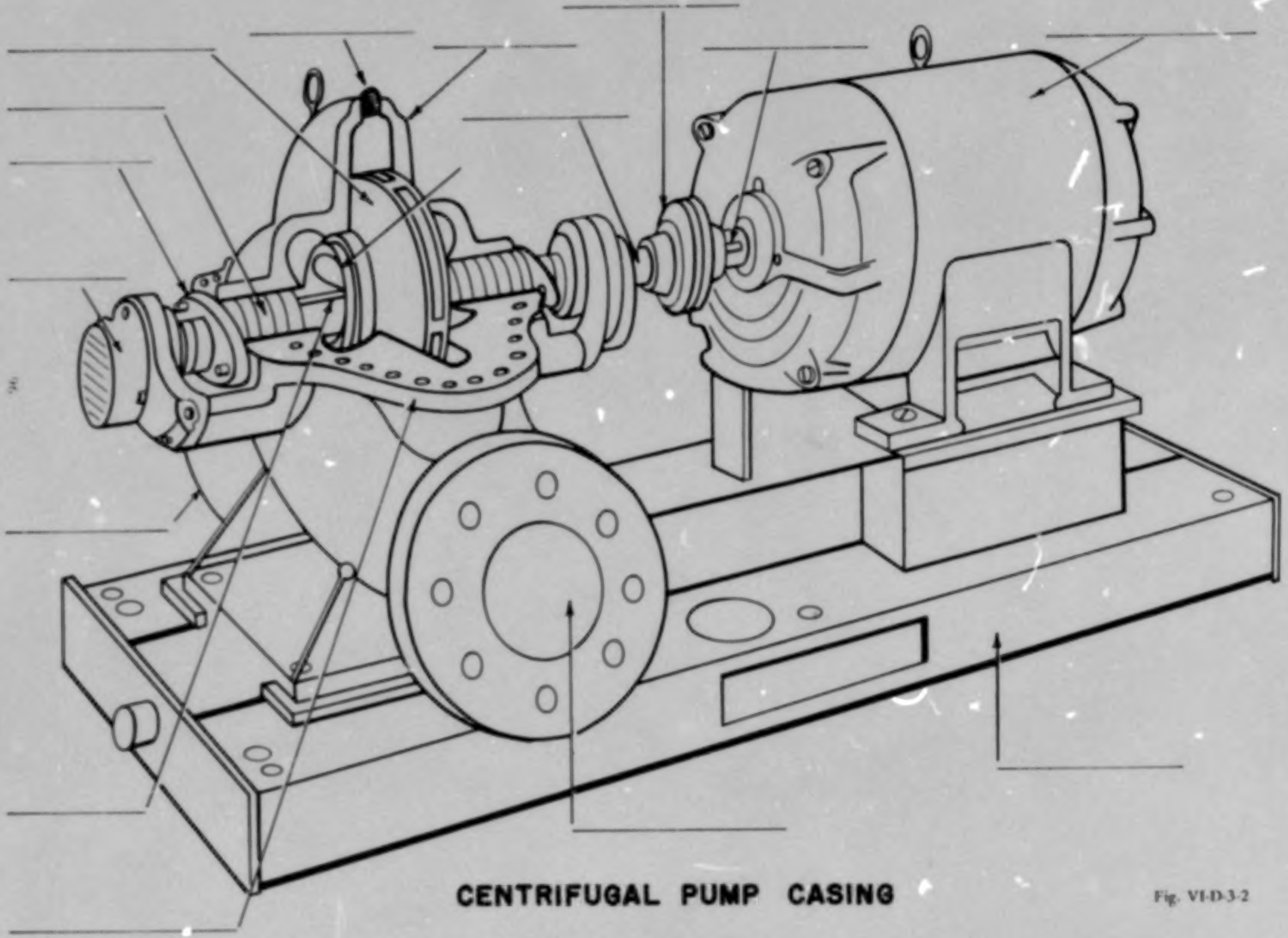
Assignment:

1. How does a centrifugal pump work?
2. What is the purpose of a centrifugal pump?
3. Name the parts of a centrifugal pump and describe the function of each.
4. Can any centrifugal pump be used for any application or service? Explain your answer.


BEARING ASSEMBLY
VOLUTE
DISCHARGE
COUPLER
IMPELLER
MOTOR
SUCTION
BASE
PUMP SHAFT

CENTRIFUGAL PUMP

Fig. VI-D-3-1



CENTRIFUGAL PUMP CASING

Fig. VI-D-3-2

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with the theory of operation.
2. Know the purpose and location of the rotary and vacuum pumps.
3. Know the parts of a rotary pump.

Information: Most rotary pumps are positive displacement units, which means that a given quantity of liquid is discharged for each revolution of the shaft. Rotary pumps may be divided into four classifications:

a. cam
b. screw
c. gear
d. vane

Each of the following is a particular type of rotary pump.

Rotary pump – gear type have two or more gears in a casing. During rotation the liquid fills the spaces between the gear teeth on the suction side. Then it is carried around and squeezed out as the teeth mesh on the outside of the pump.

Sliding vane – rotary pump with the rotor set off-center in the casing. The vanes move in and out of the rotor. The rotor turning counter-clockwise forms a cavity at the rotor bottom and the casing wall into which the liquid flows. As the pump continues to rotate the liquid is forced around and out the pump discharge. Centrifugal force holds the vanes against the inner wall of the casing.

Screw pump – draws the liquid into one or both ends of the rotor or rotors where it is trapped in the pockets formed by the threads. The liquid is moved along to the discharge point much like a nut on a thread. Screw-type rotary pumps may have one, two, or three screws.

A broad description of a rotary pump and how it operates is: it contains gears, cams, vanes, or lobes working in a casing operating with close clearances between the casing and rotating parts. These pumps have positive displacement equal to the impeller displacement and are usually low speed and positive in action. They are self priming and operate on a high suction lift discharging at a smooth flow. Identify the parts of the gear rotary pump in Figure VI-D-4-3.

Rotary pumps are suitable for handling viscous liquids which are difficult to handle with other pumps. They have close mechanical clearances and are well suited for handling liquids that lubricate or those that are volatile. Some applications would be: kerosene, benzene, gasoline, alcohol, shellac, paints, soap solutions, transformer oil, lubricating oil, fuel oil, tar, and creosote.

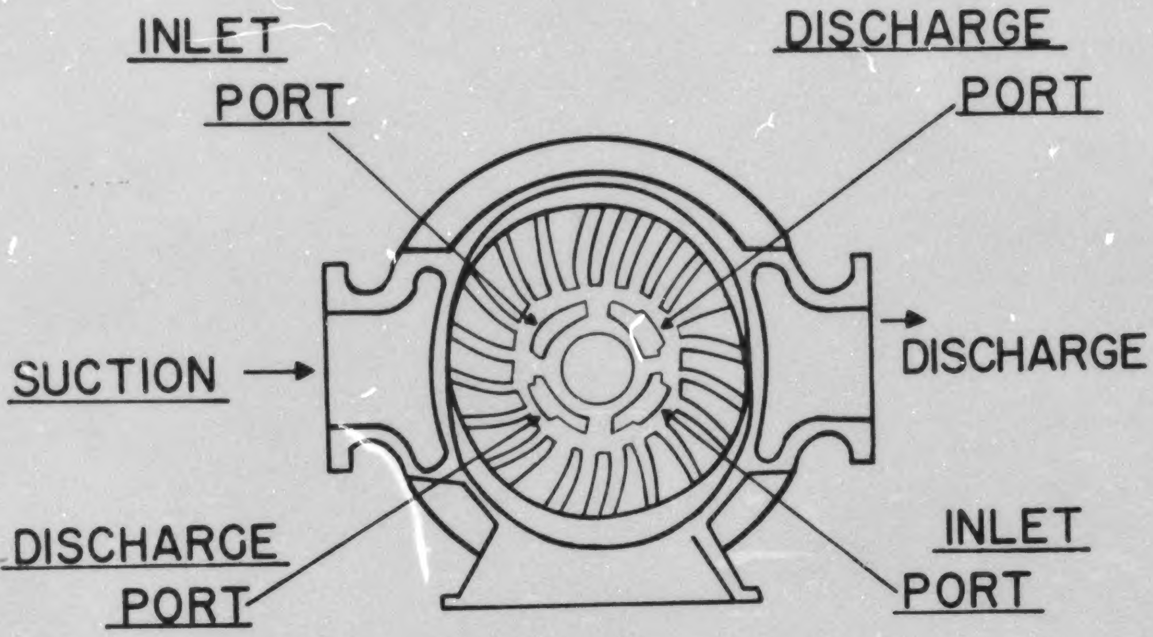
Vacuum pumps are used to remove air and water from condensate return lines. The air is discharged to the atmosphere and the water to the feed water system. Removal of air and water from the heating system is accomplished by the vacuum created on the suction side of the pump. These pumps are located with a condensate tank or vacuum tank.

References: Manufacturers' data sheet and catalogs
Practical Power Service Library
Steam Plant Operation

Procedure: Study the listed references; then do the following assignment and be prepared to discuss each.

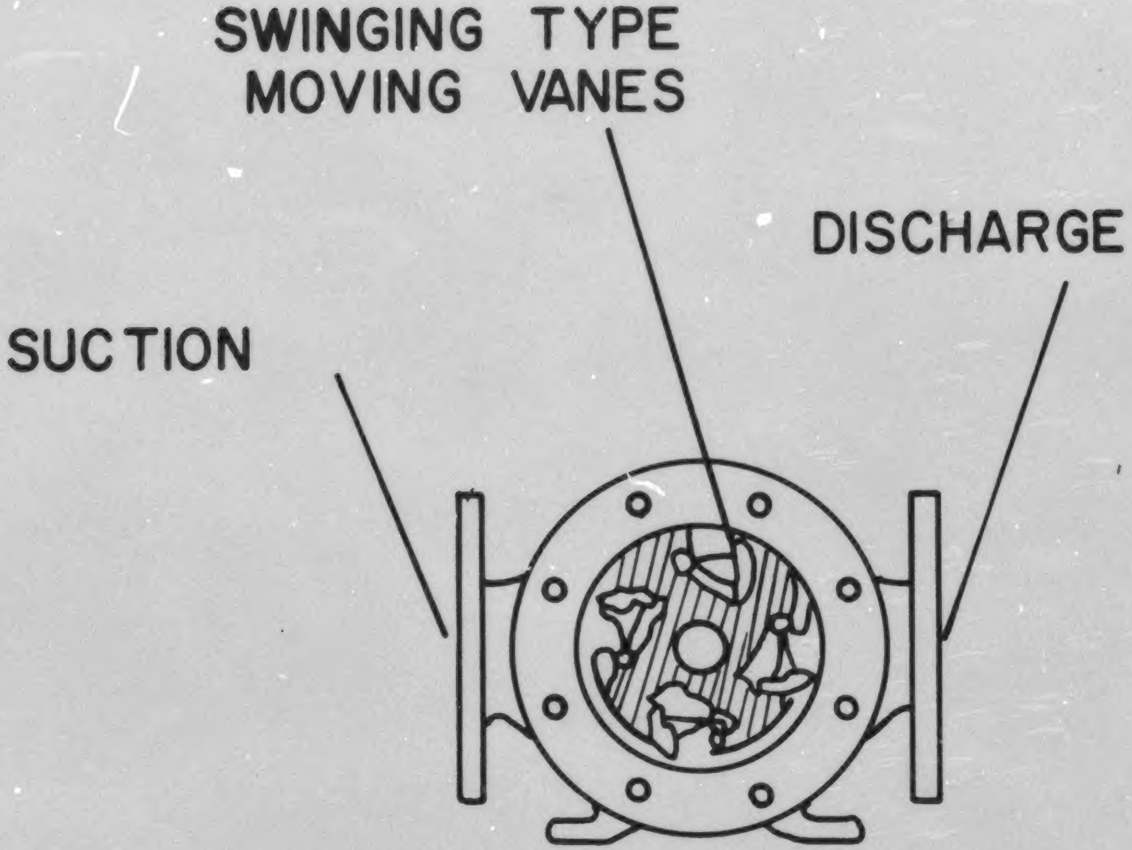
Assignment:

1. Explain how a rotary pump operates.
2. Name some different types of rotary pumps.
3. What kind of liquids can a rotary pump handle? Name some.
4. What are some of the parts found on a rotary pump?
5. What is the purpose of a vacuum pump and where is it located?
6. What is meant by the term positive displacement pump?


INLET PORT
DISCHARGE PORT
SUCTION
DISCHARGE
DISCHARGE PORT
INLET PORT

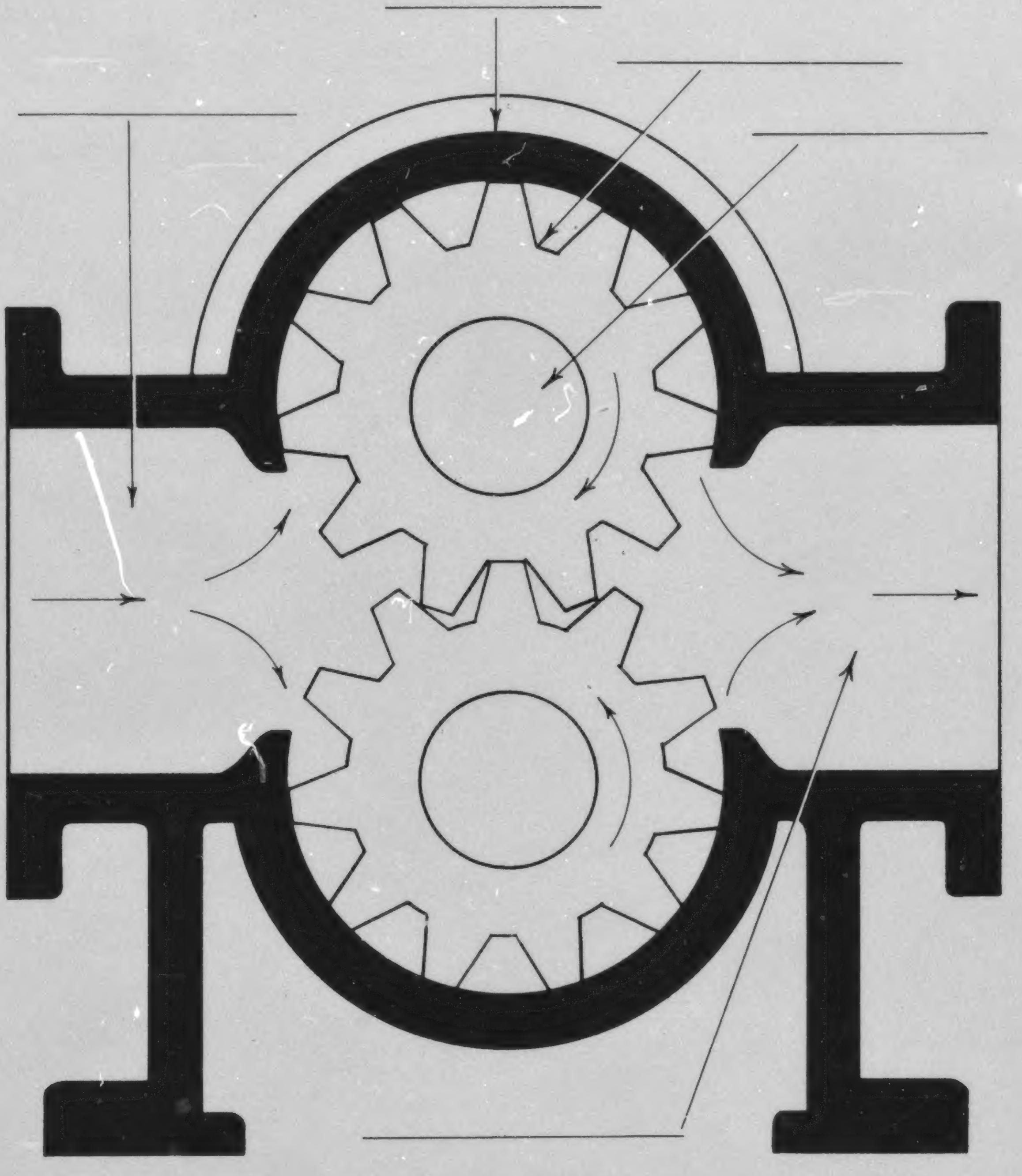
VACUUM PUMP

Fig. VI-D-4-1


SWINGING TYPE MOVING VANES
DISCHARGE
SUCTION

ROTARY PUMP

Fig. VI-D-4-2



GEAR PUMP

Fig. VI-D-4-3

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of the feed-water system.
2. Know the purpose and location of all the equipment found in the system.
3. Understand the importance of knowing the system intimately.
4. Understand the danger of low water.

NOW WHERE DID I READ ABOUT HOW TO HANDLE LOW WATER?
HEADS
OR TAILS
WON'T WORK IN A BOILER ROOM!

Information: "Water, Water everywhere and all the boards did shrink -
Water, Water everywhere nor any drop to drink!"

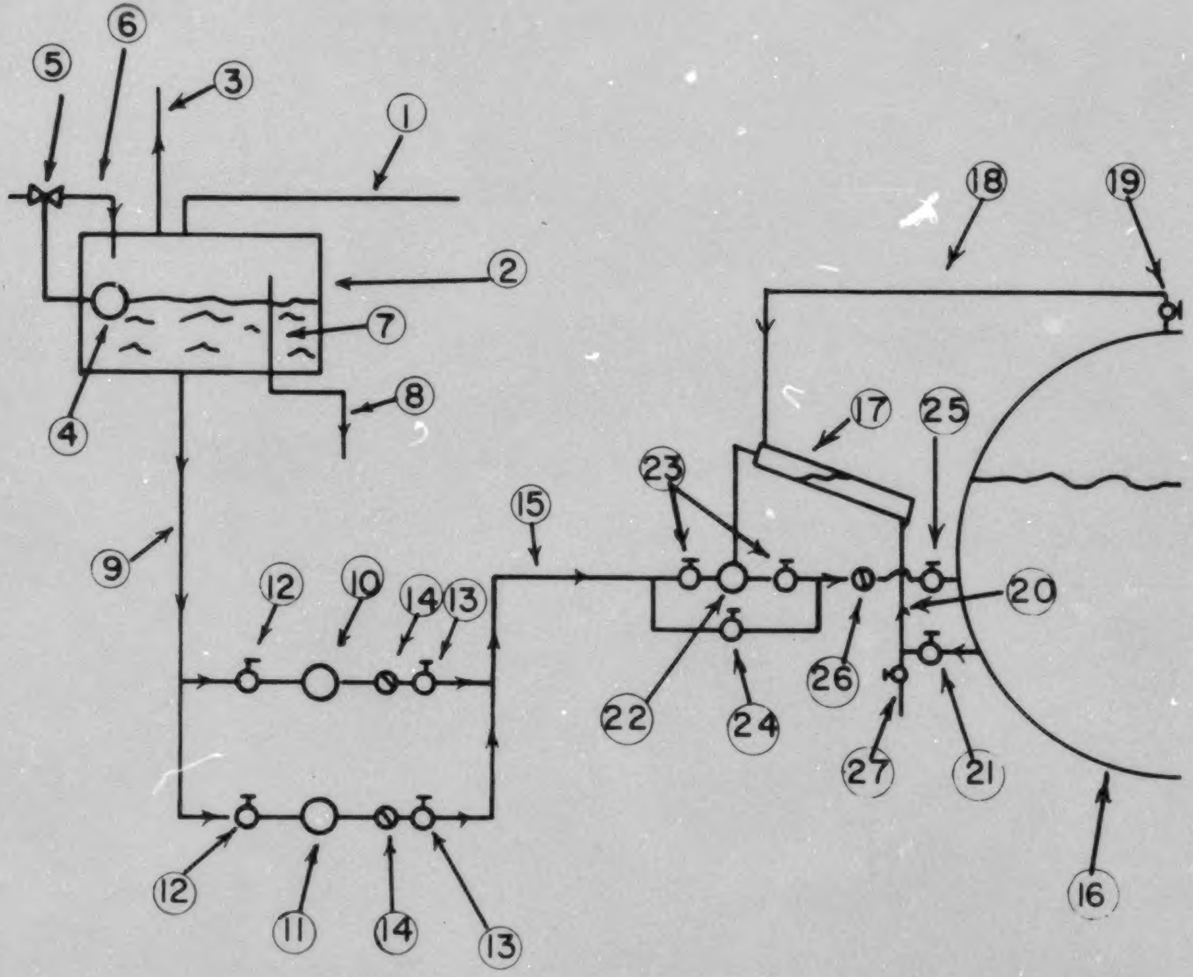
If you think the Ancient Mariner was thirsty, wait until you try keeping a high pressure boiler satisfied. It takes 1 pound of water to make 1 pound of steam. If your boiler is generating 20,000 pounds of steam per hour you must supply it with 20,000 pounds of water per hour. Water weighs about 8.3 pounds per gallon. That means about 2,410 gallons of water per hour. This should give you some idea of the importance of your feed water system and why it is necessary to know the purpose and location of all its parts.

A fireman must know of every possible way of getting water to his boilers. HEADS OR TAILS WILL NOT WORK IN A BOILER ROOM. A steaming boiler can, in a matter of minutes, have the water in the gage glass go from a half a glass to an empty glass. A boiler that is on the line and loses its water could burn up or possible explode causing untold damage and loss of life.

Look at the sketch on the next page of a basic feed water system.

The returns from the system (1) enter the feed water heater (2). Oxygen and other non-condensable gases are vented to the atmosphere (3). All the steam does not return to the feed water heater as condensate; some is lost due to leaks or process. A float (4) opens a valve (5) located on a city water line (6) to add make-up water. To prevent the feed water heater from becoming water logged there is an internal overflow line (7) which will discharge to waste (8). The feed water heater is located above the feed water pumps so that the water is supplied to the pumps through the suction line (9) at a slight head pressure. The feed water pump (10) is an electric centrifugal pump and the second feed water pump (11) is a steam driven turbine centrifugal pump. This allows the plant to be more flexible. Each feed water pump will have its own set of suction valves (12) and discharge valves (13). This would allow either pump to be taken out of service for repairs. Each feed water pump will also have its own check valve (14) to prevent water from backing up in the event the check valve (26) located close to the boiler should fail. The feed water leaves the pump through a discharge line (15).

In order to maintain a proper water level in the boiler (16) an automatic feed water regulator is used. The one in the sketch is a Copes-type regulator. It is a mechanical type regulator that works on expansion and contraction of an inclined tube (17). The inclined tube is located at the normal operating water level. The top is connected by a line (18) that goes to the highest part of the steam side of the boiler. There is a shut-off valve (19) so that the regulator may be taken out of service for repairs. The bottom of the inclined tube is connected to the boiler by a line (20) that is well below the normal operating water level. The shut-off valve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BASIC FEED-WATER SYSTEM
HIGH PRESSURE

Fig. VII-A-1-1

(21) is also used when making repairs. The inclined tube is fixed at the back and cannot move. It is, however, free to expand and contract at the top and is connected by linkage to a valve (22) located in the feed water line (15). The feed water valve (22) has two shut-off valves (23) so that the valve may be taken out of service if it fouls up. The water would then go through the bypass valve (24). This would prevent taking the boiler off the line because of a regulator failure. On the feed water line you will notice a stop valve (25) and a check valve (26). The stop valve is located closest to the shell of the boiler so that the check valve (26) could be repaired if need be without dumping the boiler. The Copes regulator is equipped with a blowdown valve (27) to insure the water lines are free and clear of sludge and sediment.

Reference: *Steam Plant Operation*

Boiler Room Questions and Answers

Procedure: After having read the information and studied the listed references, answer the following questions and be prepared to discuss each in class.

Assignment:

1. Why is makeup water needed and how is it added to the system?
2. What is the purpose of a check valve and where are they found in the system?
3. Why is a stop valve placed in the feed-water line closest to the shell of the boiler?
4. If a Copes regulator failed to open, how could you get water to your boiler?
5. What prevents water from backing up into the return lines?

Objectives: Upon completion of this lesson, the student will be able to:

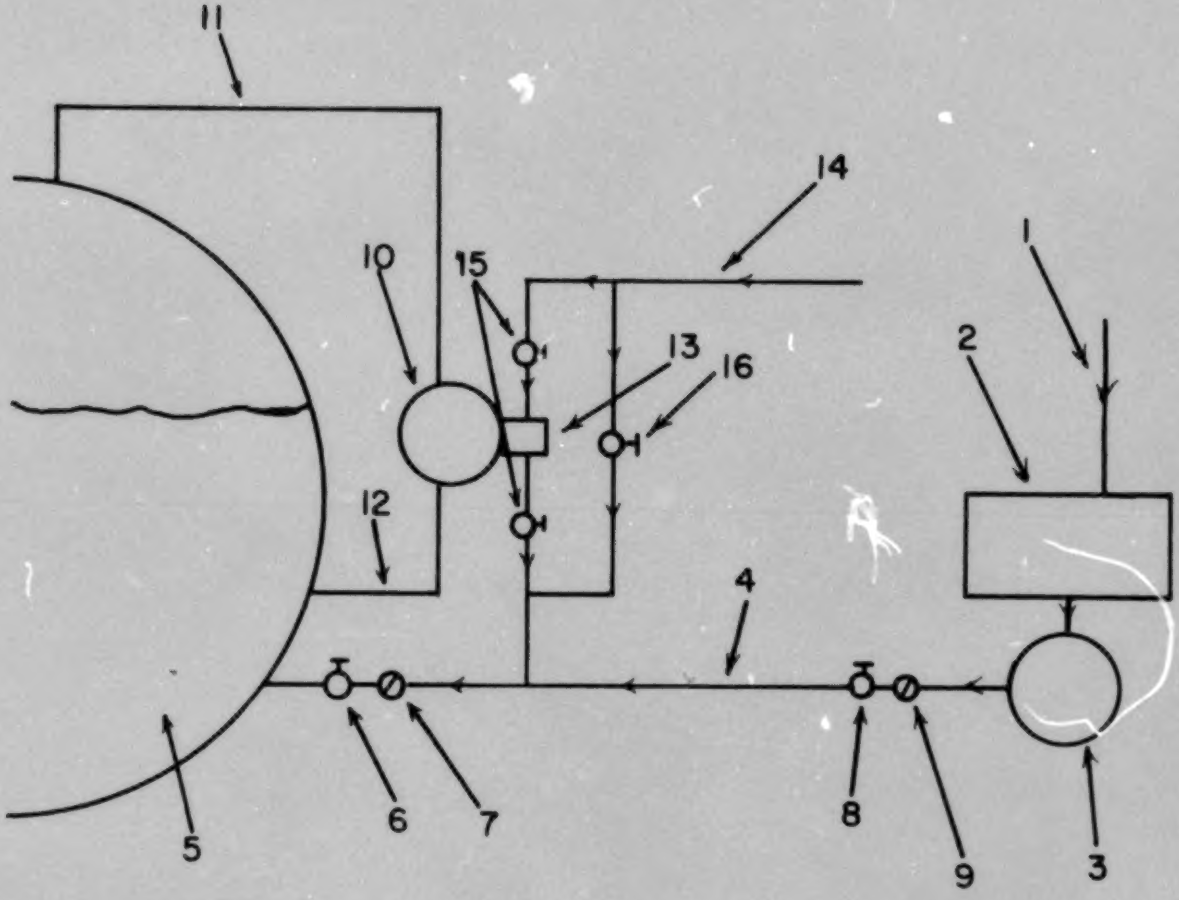
1. Know the purpose of the feed-water system.
2. Identify and describe the purpose of the equipment found in the system.
3. Explain the importance of a complete knowledge of the system.
4. Explain why low water is dangerous.

Information: In Unit VII-A-1 we covered the feed-water system of a high-pressure boiler. We discussed the purpose of the feed water system, the importance of being thoroughly familiar with the system, and the danger of low water. These facts hold true for a low pressure feed water system. The difference between the two will be the equipment found in the system.

The sketch in Figure VII-A-2-1 should be carefully studied.

When steam gives up its heat it turns back to water called condensate. The condensate is brought back to the boiler room by condensate return lines (1) and enters the vacuum tank (2). The vacuum pump (3) discharges the water through feed water lines (4) back to the boiler (5). On this feed water line you will notice located as close to the boiler shell as practical a stop valve (6). The stop valve is there so that the check valve (7) may be repaired without having to dump the boiler. It is customary to install another stop valve (8) and check valve (9) close to the vacuum pump as an added precaution. Without the check valve the water would be forced out of the boiler through the vacuum pump into the vacuum tank and back into the return line when the vacuum pump stops. If for some reason the condensate returns fail to come back to the vacuum tank the water level in the boiler would start to drop. This could lead to a serious low water condition. To prevent this an automatic city water makeup control (10) is installed a little below the normal operating water level. The top line (11) connects to the highest part of the steam side of the boiler and the bottom line (12) connects well below the normal operating water level. If the water level drops in the boiler the float in the city water makeup drops and opens a needle valve (13) connected to the city water line (14) allowing city water to enter the boiler. A pair of stop valves (15) are installed one before and one after the needle valve so that it may be serviced if necessary. There is also a bypass valve (16) so that city water can be added by hand.

I'm sure that if you compare the sketch in VII-A-1 with this sketch you will be able to see where the systems are the same and where they differ.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BASIC FEED-WATER SYSTEM
LOW PRESSURE

Fig. VII-A-2-1

Reference: *Low Pressure Boilers*, Chapter 3

Procedure: After having studied the reference and the sketch, answer the following questions and be prepared to discuss each in class.

Assignment:

1. What is the purpose of a stop and check valve in the system? Why is their position so important?
2. Describe in detail how the vacuum pump is controlled. (What makes it start and stop?)
3. What prevents a low water condition in a low-pressure boiler?
4. How many ways can city water makeup be added in the low-pressure system discussed?
5. Why do you think it necessary to have a bypass valve around the automatic city water makeup?

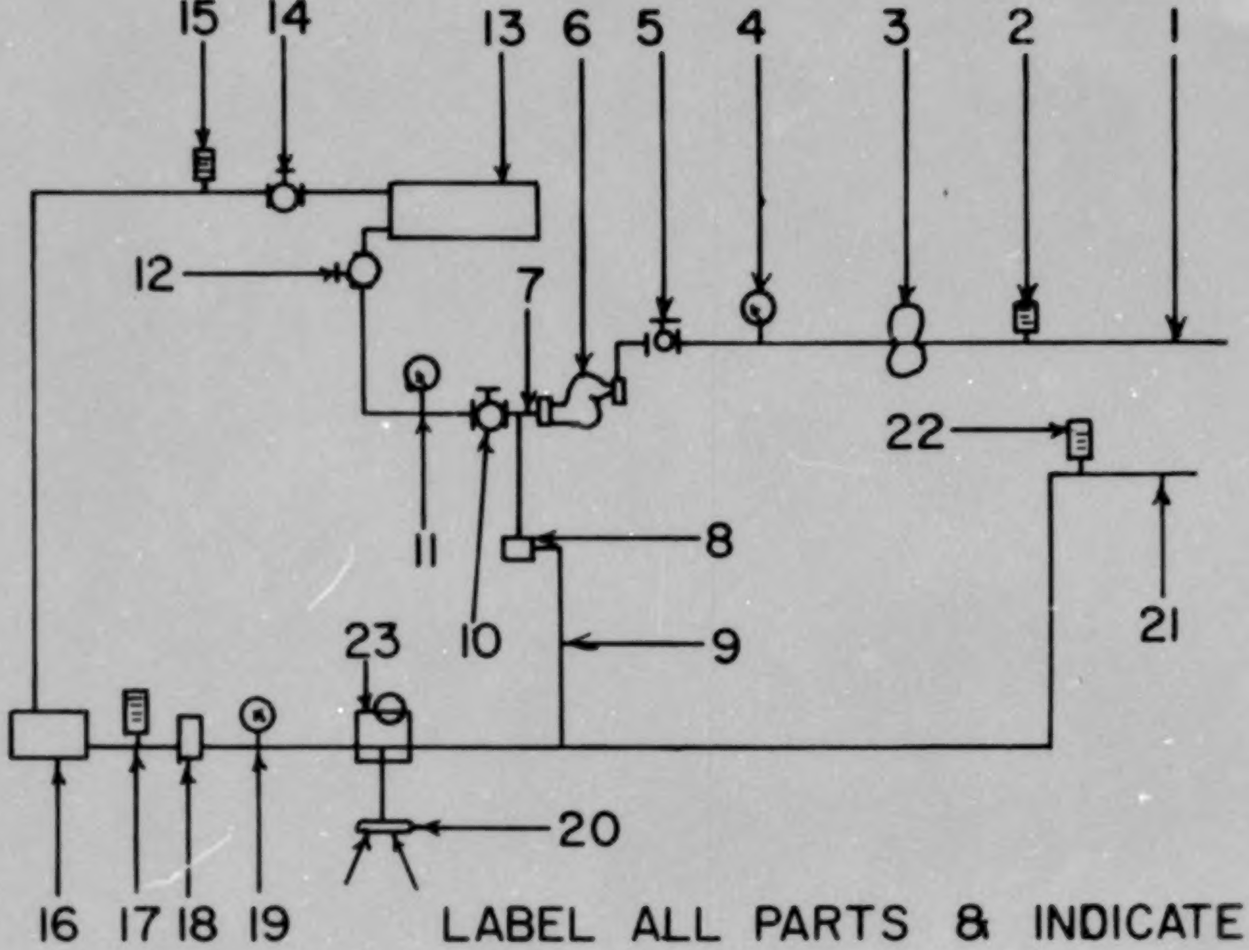
Objectives: Upon completion of this lesson, the student will:

1. Be familiar with a basic fuel oil system.
2. Be able to identify the parts of a fuel oil system.
3. Know the purpose of the parts of the fuel oil system.

Information: The purpose of any fuel oil system is to get the fuel oil to the burner at the proper temperature and pressure. This means that we must pump, heat, and regulate the fuel oil before it gets to the burner. Once the oil gets to the burner, it is a function of the burners to properly fire the fuel into the combustion chamber of the boiler. The burner will be discussed at a later time.

The fuel oil system consists of various parts and we start with the storage tank and suction line (1). In our system we have two twenty-thousand gallon fuel oil tanks located in the rear of the building under the black top. In order to pump this fuel oil it must be heated. This is accomplished by a steam heating bell located in the fuel oil tank. To give us an indication of the temperature of the oil coming from the tank there is a thermometer (2) located on the suction line. The duplex strainer (3) permits one strainer to be cleaned while the other is in service. The suction gage (4) shows how many inches of vacuum the fuel oil pump is pulling. The suction valve (5) and the discharge (9) located before and after the fuel oil pump allows you to isolate the pump from the system. The fuel oil pump (6) moves the oil from the storage tank through a discharge line (7). The relief valve (8) protects the system from excessive oil pressure and discharges back to the fuel oil return line (9). A pressure gage (11) indicates the fuel oil discharge pressure. The fuel oil is further heated by a steam fuel oil heater (13). An inlet valve (12) and an outlet valve (14) allow you to isolate the heater. A thermometer (15) indicates the temperature of the oil leaving the heater. The oil then goes to an electric heater (16) where the oil is brought up to the temperature it is to be burned at.

A thermometer (17) shows the temperature of the oil after it leaves the electric heater. A simplex strainer (18) is used to collect any impurities or dirt left in the oil. A pressure gage (19) indicates the pressure of the oil at the burner (20) which is regulated by an oil pressure regulator (23). Not all the oil is burned, and some is recirculated through a return line (21). A thermometer (22) shows the return oil temperature to the fuel oil storage tank.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LABEL ALL PARTS & INDICATE DIRECTION OF OIL FLOW

Fig. VII-B-1-1

SIMPLE FUEL OIL CYCLE

Reference: *Low Pressure Boilers*, p. 74

Procedure: After having studied the above information and reference material, do the following assignment and be prepared to discuss each in class.

Assignment:

1. Label the parts of the fuel oil system as shown on the attached sketch.
2. On a separate sheet explain the purpose of all parts of the system.

Objectives: Upon completion of this lesson, the student will:

1. Know how a fuel oil tank is calibrated.
2. Be able to compute fuel oil readings.
3. Be able to compute fuel oil consumption.

Information: The fireman and engineer is responsible for the maintaining of boiler room records and readings. He must be able to figure fuel oil consumption and keep records of all oil used per hour, per day, per week, or per year.

Fuel oil tanks may be equipped with a fuel gage which will give you the gallons of oil in the tank. If a gage is not installed or if it is faulty you must be able to sound the tank and figure the oil it contains from a chart. When you sound the tank you will get a reading in feet and inches. Looking at sketch VII-B-2-1 it should be clear that 1" of oil at point "A" would not be the same number of gallons as at point "B" or at point "C".

Example: Stick sounding Monday – 5' 6"
Tuesday – 5' 2½"

Find: 1. – oil in tank Monday
2. – oil in tank Tuesday
3. – oil consumed

Monday Reading:
Change feet to inches
5 × 12 = 60"
60 + 6 = 66"

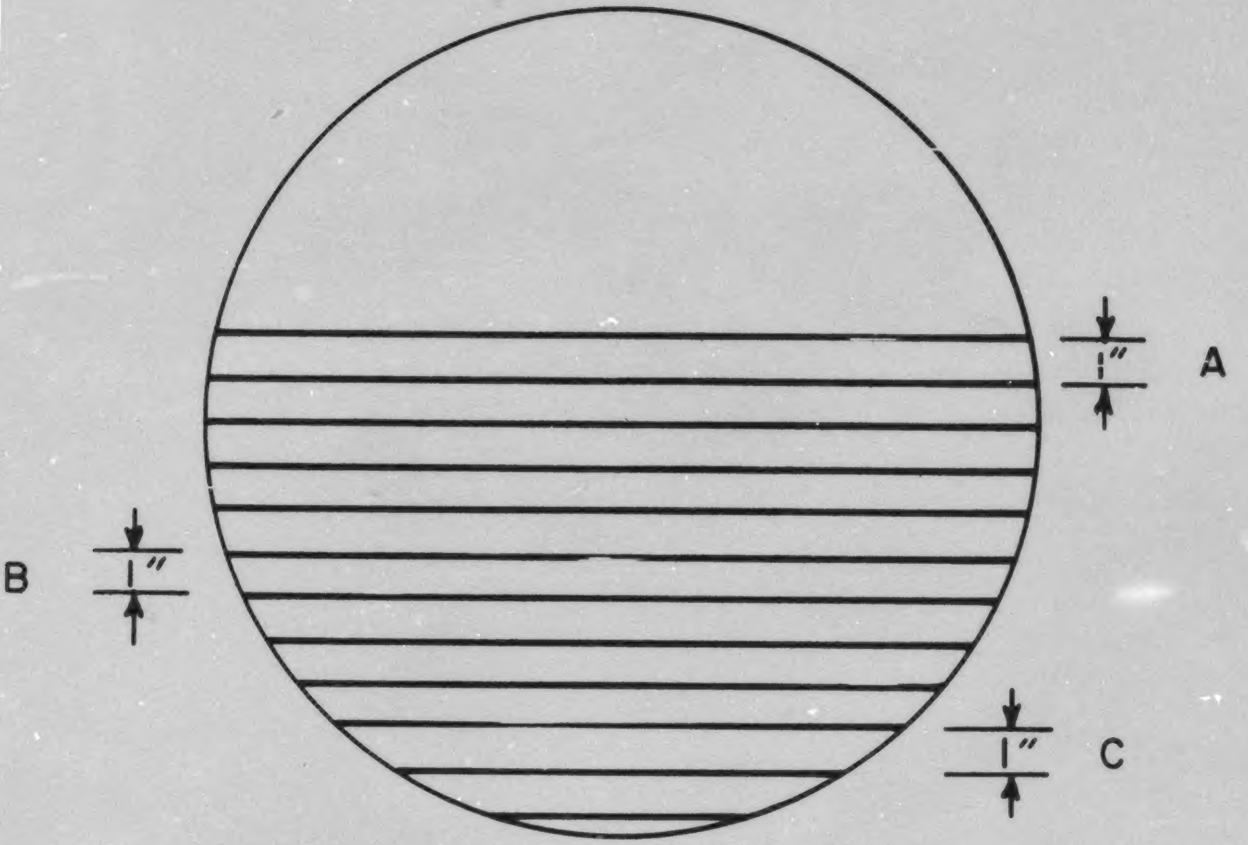
Using the chart for tank, 66" = 10,648 gals.

Tuesday Reading:
Change feet to inches
5 × 12 = 60"
60 + 2½ = 62½"

Note: There is no reading on the tank chart for ½" of oil. It will be necessary to interpolate:

Find gals. 63" = 10,040
Find gals. 62" = 9,837
Subtract 203 gals. per inch
Take ½ = 101.5 gals. per ½"

Gals. at 62" = 9,837
add + 101.5
Gals. at 62½" = 9,938.5
add + 101.5
Gals. at 63" = 10,040.0



Tank sketch showing 1" of oil

Fig. VII-B-2-1

Oil reading Monday 10,648
Oil reading Tuesday – 9,938
Oil used 710 gals.

1. Oil in tank Monday 10,648 gals.
2. Oil in tank Tuesday 9,938 gals.
3. Oil used 710 gals.

Procedure: After having studied the example, do the following assignment.

Assignment: Using the following fuel oil chart find the gallons of oil for the following readings:

1. Stick sounding – 4′ 4½″. How much oil is in the tank?
2. Stick sounding: Friday 8 A.M. – 6′ 8″
   Monday 8 A.M. – 5′ 3″
   Find: a. total gals. burned
   b. gals. burned per day
3. Stick sounding: Monday – 3′ 3½″, received oil delivery – reading after drop 6′ 8″.
   Find: gallons of oil delivered
4. Stick sounding: 9/1 Monday 8 A.M. – 8′ 6″
   9/2 Tuesday 8 A.M. – 8′ 2½″
   9/3 Wednesday 8 A.M. – 7′ 11″
   9/4 Thursday 8 A.M. – 7′ 4½″
   9/5 Friday 8 A.M. – 5′ 6″
   9/8 Monday 8 A.M. – 4′ 10½″

   Find: a. fuel burned daily from 9/1 to 9/5
   b. fuel burned 9/5 to 9/8 (total)
   c. fuel burned per day 9/5 and 9/8
   d. total gallons consumed from 9/1 to 9/8

Calibration Chart Tank #1

Inches	Gallons	Inches	Gallons	Inches	Gallons
1	26	41	6039	81	14446
2	72	42	6241	82	14647
3	131	43	6446	83	14844
4	201	44	6641	84	15041
5	281	45	6858	85	15236
6	368	46	7066	86	15428
7	463	47	7275	87	15620
8	565	48	7485	88	15810
9	672	49	7694	89	15997
10	787	50	7904	90	16183
11	906	51	8116	91	16367
12	1030	52	8350	92	16548
13	1159	53	8542	93	16727
14	1292	54	8756	94	16904
15	1431	55	8978	95	17077
16	1572	56	9181	96	17249
17	1718	57	9395	97	17417
18	1868	58	9610	98	17583
19	2021	59	9825	99	17745
20	2177	60	10038	100	17906
21	2337	61	10253	101	18058
22	2500	62	10468	102	18210
23	2665	63	10681	103	18359
24	2833	64	10896	104	18507
25	3004	65	11108	105	18647
26	3178	66	11322	106	18785
27	3354	67	11540	107	18920
28	3533	68	11752	108	19047
29	3715	69	11964	109	19172
30	3898	70	12176	110	19291
31	4085	71	12386	111	19404
32	4272	72	12597	112	19512
33	4462	73	12807	113	19614
34	4652	74	13015	114	19708
35	4846	75	13223	115	19799
36	5041	76	13430	116	19875
37	5236	77	13635	117	19945
38	5435	78	13841	118	20005
39	5634	79	14044	119	20052
40	5836	80	14257	120	20078

20,000 gallon tank 10′ dia., 34′ 3″ long flat heads

Objectives: Upon completion of this lesson, the student will:

1. Know what is meant by draft.
2. Be able to explain why draft is necessary in a boiler.
3. Be able to measure draft.

Information: Draft may be defined as a difference in pressure which will cause an air flow. This air is essential for combustion. It takes about 15 pounds of air to burn one pound of fuel. In order for us to burn our fuel properly we need sufficient quantities of air under enough pressure to overcome the resistance caused by breeching, dampers, baffles, tube passes, economizers, and superheaters.

Draft is measured in inches or tenths of an inch of water column. It is the difference in height in two legs of a glass tube. See sketch VII-C-1-1 and VII-C-1-2. In order to convert inches of water to pounds per square inch we proceed as follows:

We know 1 cu.ft. of water weighs 62.4 pounds. The weight of water will vary with temperature, but the temperature ranges we will be working in make the changes so slight they need not be considered.

1 cu.ft. = 1,728 cubic inches

$\frac{62.4}{1728}$ = .0361 p.s.i. The pressure in pounds per square inch indicated by a column of water 1″ high.

See sketch VII-C-1-3

The sketch will give you an idea of how the pressure will vary with the height of water. Note that at 12″ the pressure is .433 pounds. This figure is one to remember; it will be referred to in other lessons.

Reference: *Low Pressure Boilers*

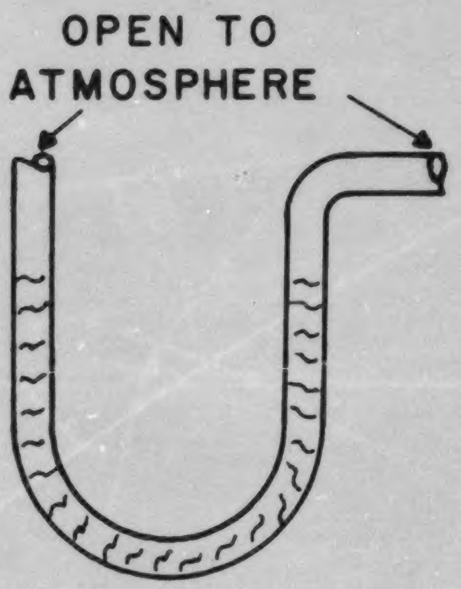
Boiler Room Questions and Answers

Steam Plant Operation

Procedure: After having studied the information and listed references, answer the following questions and be prepared to discuss each in class.

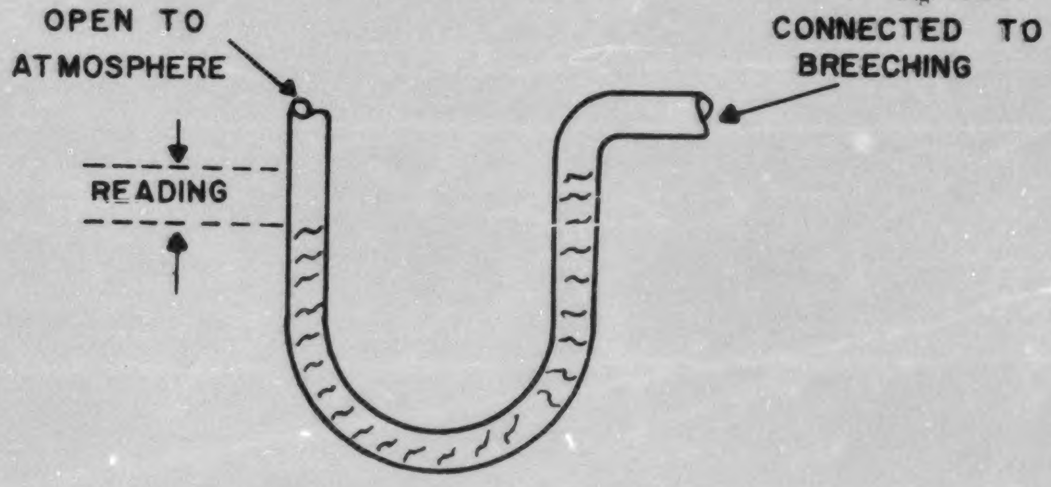
Assignment:

1. What is draft and why is it necessary in a boiler?
2. Explain the operation of a U-tube draft gage.
3. In what units is draft measured?
4. Approximately how many pounds of air is needed to burn 1 pound of fuel?
5. Using the comparison chart, how much pressure will 2″ of water exert? How much pressure at 12″?


OPEN TO
ATMOSPHERE

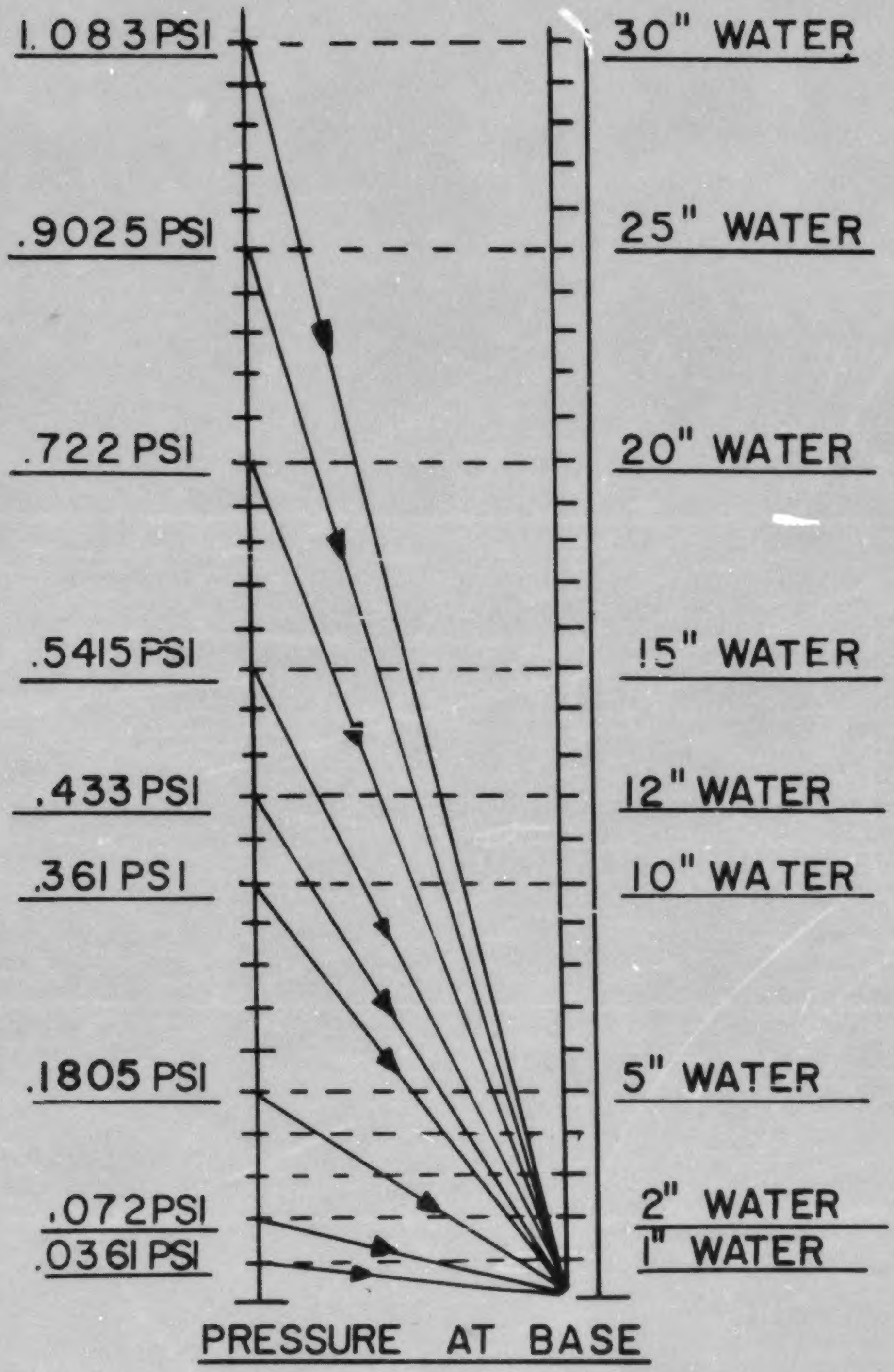
MANOMETER MEASURES DRAFT WITH U-TUBE TYPE GAGE. BOTH LEGS ARE EQUAL LEVEL AT ATMOSPHERIC PRESSURE.

Fig. VI-C-1-1


OPEN TO
ATMOSPHERE
CONNECTED TO
BREECHING
READING

DRAFT GAGE CONNECTED TO BREECHING SHOWING NEGATIVE READING. WATER RISES IN LEG CONNECTED TO BREECHING.

Fig. VII-C-1-2


1.083 PSI
30" WATER
.9025 PSI
25" WATER
.722 PSI
20" WATER
.5415 PSI
15" WATER
.433 PSI
12" WATER
.361 PSI
10" WATER
.1805 PSI
5" WATER
.072 PSI
2" WATER
.0361 PSI
1" WATER
PRESSURE AT BASE

PRESSURE AT BASE OF COLUMN OF WATER

.0361 PSI FOR EACH VERTICAL INCH

Fig. VII-C-1-3

Objectives: Upon completion of this lesson, the student will:

1. Know what natural draft is.
2. Know what mechanical draft is.
3. Know how natural draft is produced.
4. Know how mechnical draft is produced.

Information: We have been introduced to draft as it relates to a boiler. Now we will learn about the different types of draft.

The oldest form of draft that we will discuss is natural draft. Natural draft is produced by a chimney alone, without the use of any mechanical means. It is caused by the difference in weight between the column of hot gas inside the chimney and a column of cold outside air of the same height and cross section. The intensity of draft produced by a chimney depends on the height of the stack and the difference between the outside air and the inside gas temperature. The chimney gas, because it is lighter than the outside air, tends to rise; and the heavier outside air replaces this air in the furnace area of the boiler. See sketch VII-C-2-1.

The amount of natural draft can be determined by measuring the difference between two points such as the atmosphere and the inside of the boiler setting. Air leaks in the boiler; the breeching or boiler side walls dilute the chimney gasses, increase the volume, lower the temperature, and thus lower the effective draft. Natural draft is controlled by the use of dampers which control the flow of air to the burners and the gasses of combustion leaving the boiler setting. There are limitations to the application of natural draft chimneys. The trend in design of modern boiler units is toward high rates of heat transfer, which results in increased draft loss. This ultimately demands a higher chimney which becomes physically and economically impractical.

Mechanical draft is the use of power-driven fans providing a means of furnishing the necessary draft. Centrifugal fans can be built to meet the necessary requirements with either *FORCED* or *INDUCED* drafts.

Forced draft is produced by a power-driven fan forcing the air into the boiler furnace. See sketch VII-C-2-2. This is done by placing the fan at the front of the boiler.

Induced draft is the use of a power-driven fan located between the boiler and the chimney. See sketch VII-C-2-3.

There are some applications where both forced and induced draft fans are needed. See sketch VII-C-2-4.

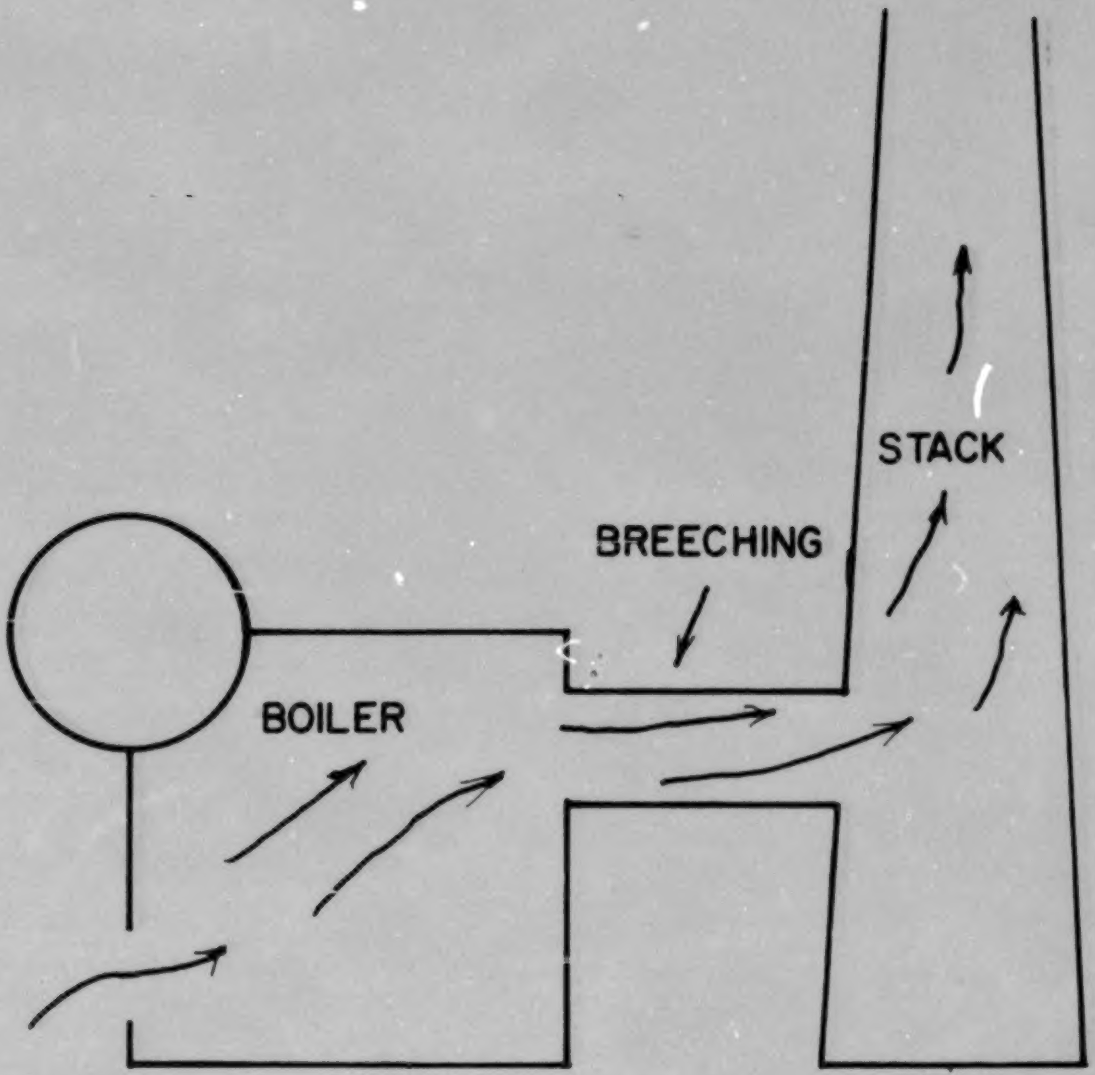
Mechanical draft can be controlled by:

- a. controlling the speed of the fan.
- b. the use of dampers.
- c. the use of inlet vanes on the fan.

Reference:
1. *Steam Plant Operation*
2. *Boiler Room Questions and Answers*

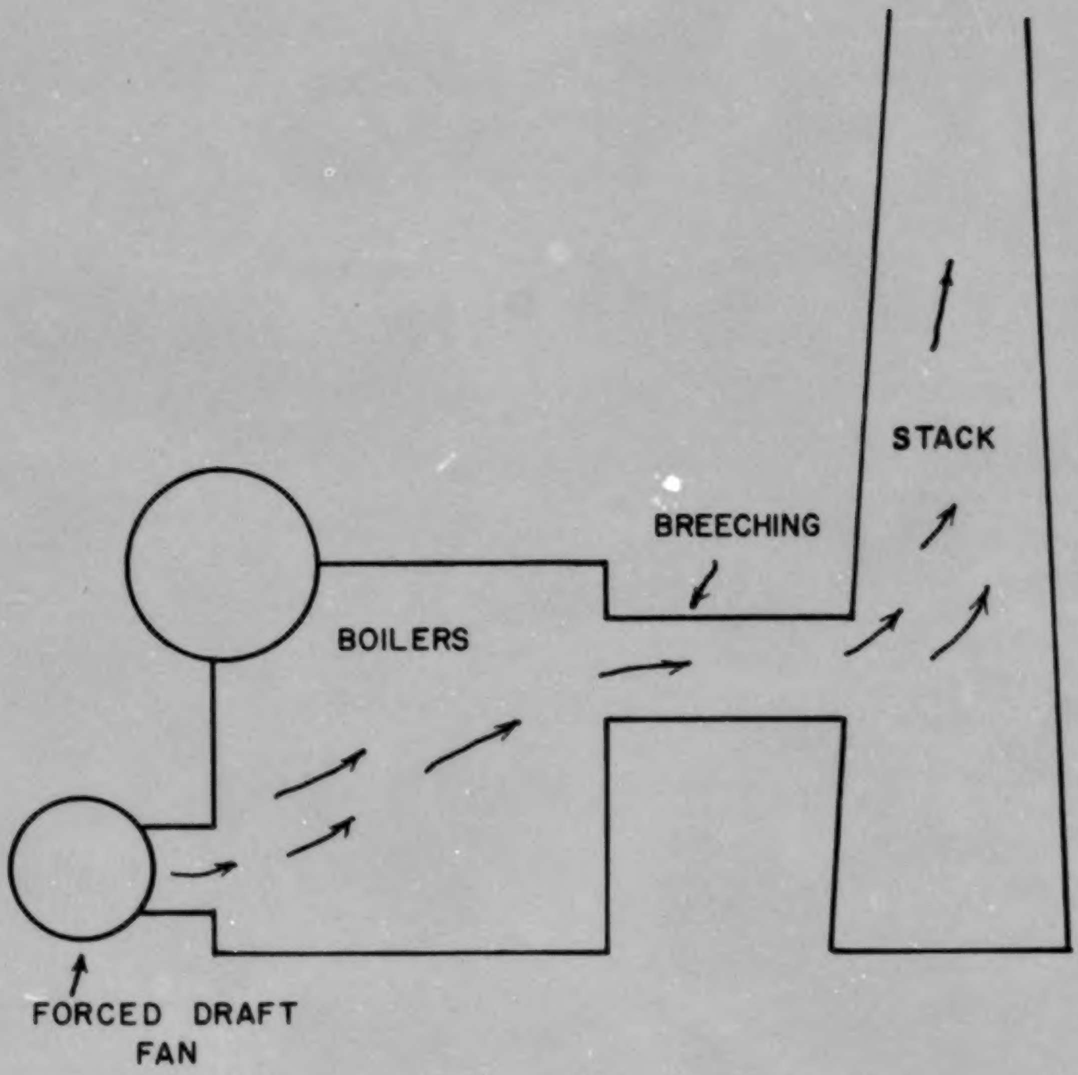
Procedure: After having studied the information and listed references, answer the following questions and be prepared to discuss each in class.

Assignment:
1. What is natural draft?
2. What is forced draft?
3. What is induced draft?
4. What are some of the conditions that make it necessary to employ mechanical draft?
5. Can you get a positive draft in the furnace? Explain your answer and discuss the safe operation of the boiler under this condition.


STACK
BREECHING
BOILER

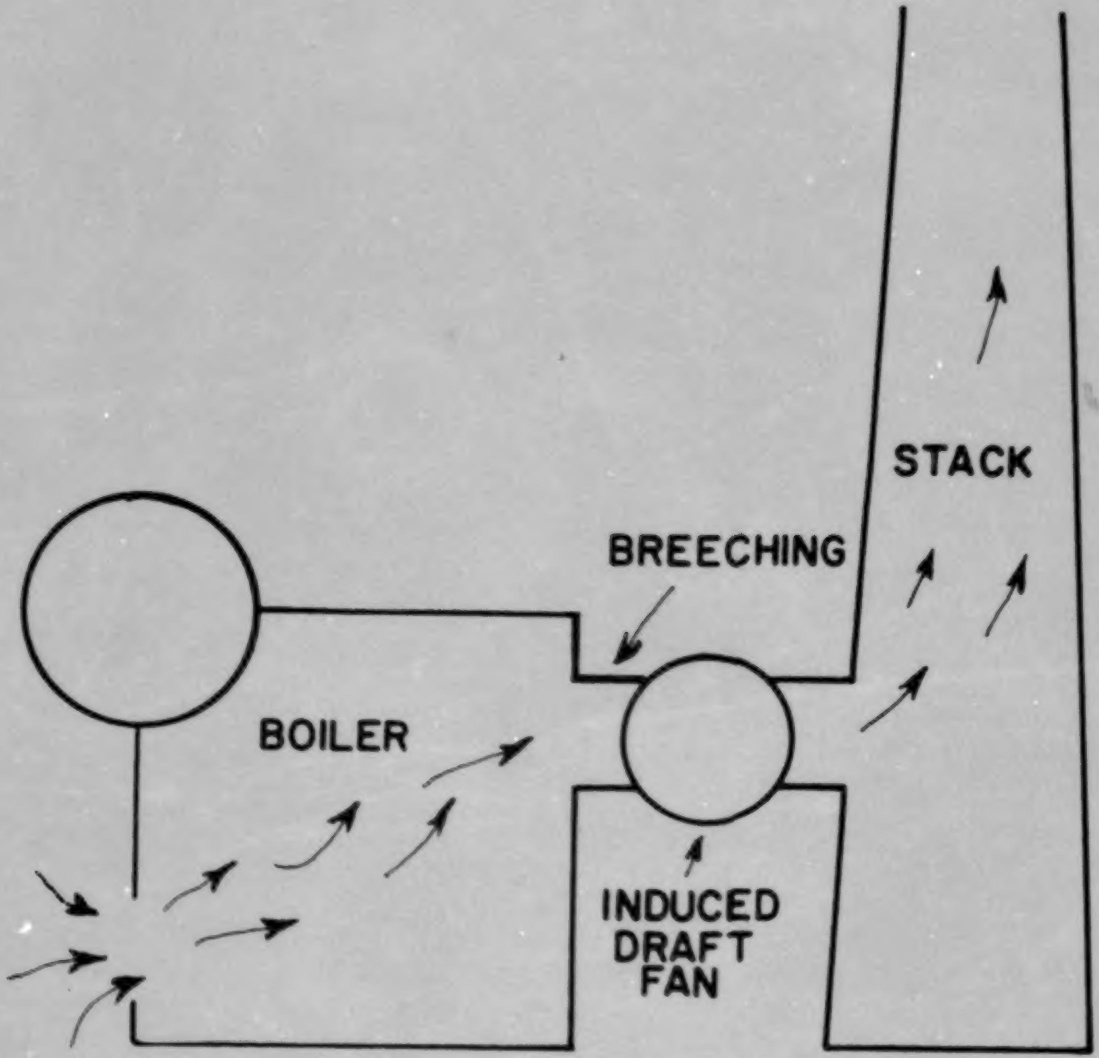
NATURAL DRAFT

Fig. VII-C-2-1


STACK
BREECHING
BOILERS
FORCED DRAFT FAN

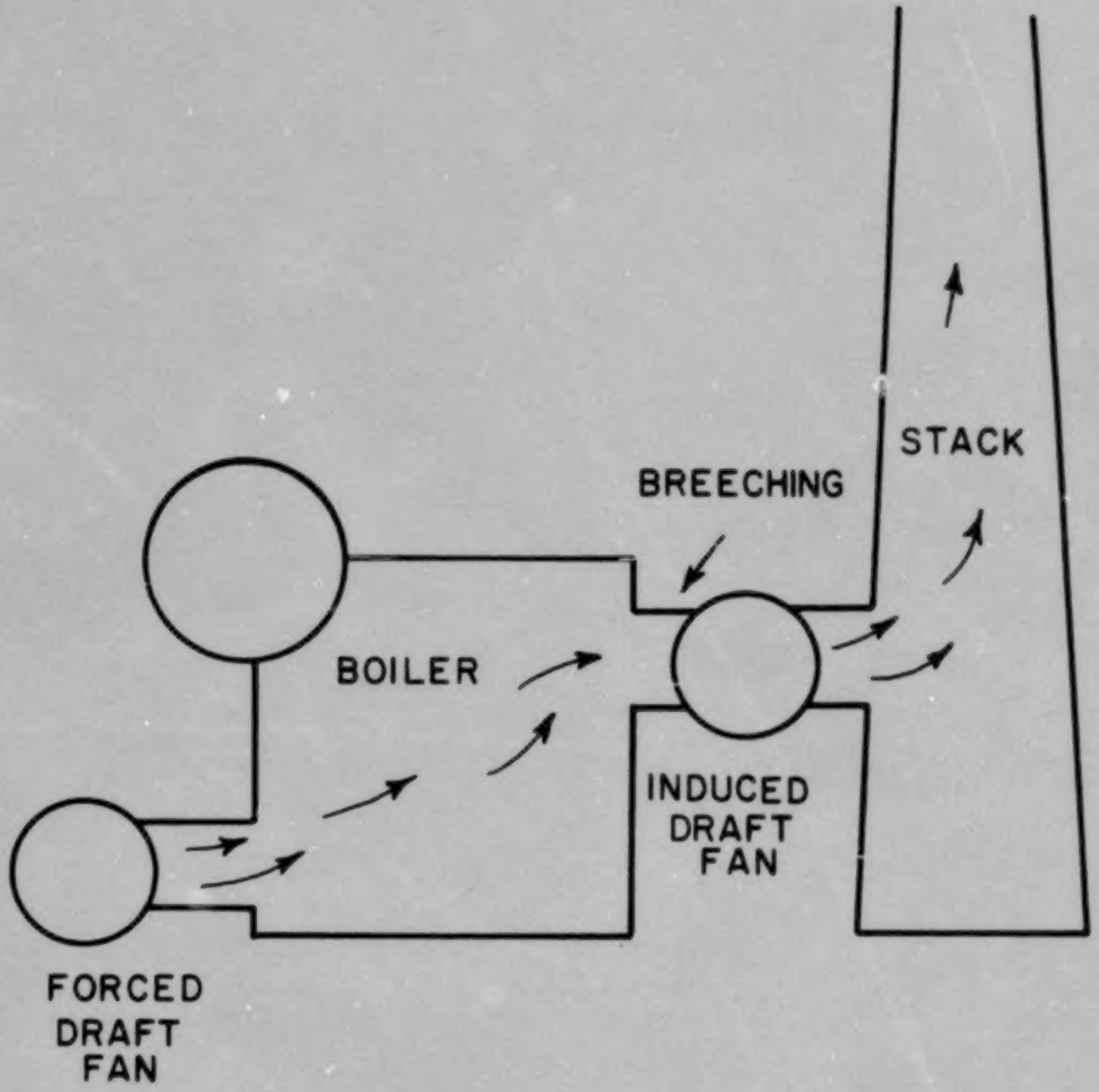
MECHANICAL DRAFT FORCED

Fig. VII-C-2-2


STACK
BREECHING
BOILER
INDUCED DRAFT FAN

MECHANICAL DRAFT
INDUCED

Fig. VII-C-2-3


STACK
BREECHING
BOILER
INDUCED DRAFT FAN
FORCED DRAFT FAN

MECHANICAL DRAFT
COMBINATION
FORCED AND INDUCED

Fig. VII-C-2-4

Objectives: Upon completion of this lesson, the student will:

1. Know the basic principles of combustion.
2. Know the basic combustion equations.

Information: Combustion may be defined as the rapid union of oxygen with an element or compound, which will result in the evolution of heat. An example of this is when the elements in a fuel combine with the oxygen in the air to produce heat. The elements in the fuel are:

a. carbon
b. sulphur
c. hydrogen
d. oxygen
e. nitrogen

Oxygen will support combustion, but it is not a combustible by itself.

Nitrogen is neither a combustible nor a supporter of combustion.

Carbon, hydrogen, and sulphur are the combustibles in a fuel; they combine with the oxygen from the air to form compounds of combustion. When carbon combines with oxygen it forms a compound of carbon monoxide or carbon dioxide. This can be shown with the following combustion equations:

$$2C + O_2 \rightarrow 2CO + \text{Heat}$$

$$C + O_2 \rightarrow CO_2 + \text{Heat}$$

When sulphur combines with oxygen it forms sulphur dioxide:

$$S + O_2 \rightarrow SO_2 + \text{Heat}$$

The above reactions are taking place in a furnace during the burning of a fuel provided there is sufficient air (oxygen) to allow it to go to completion.

Reference: *Steam Plant Operation*

Procedure: After having studied the listed reference and information, do the following assignment.

Assignment:

1. What elements in a fuel will combine with oxygen during the combustion process?
2. What elements will not combine with oxygen?
3. Show with combustion equations the combustion process of a fuel.
4. What are the end products of combustion?

$$\boxed{C} + \boxed{O_2} \longrightarrow \boxed{CO_2}$$

$$C + O_2 \longrightarrow CO_2 + \text{HEAT}$$

$$\boxed{CO}\;\boxed{CO} + \boxed{O_2} \longrightarrow \boxed{CO_2}\;\boxed{CO_2}$$

$$2CO + O_2 \longrightarrow 2CO_2 + \text{HEAT}$$

$$\boxed{H_2}\;\boxed{H_2} + \boxed{O_2} \longrightarrow \boxed{2H_2O}$$

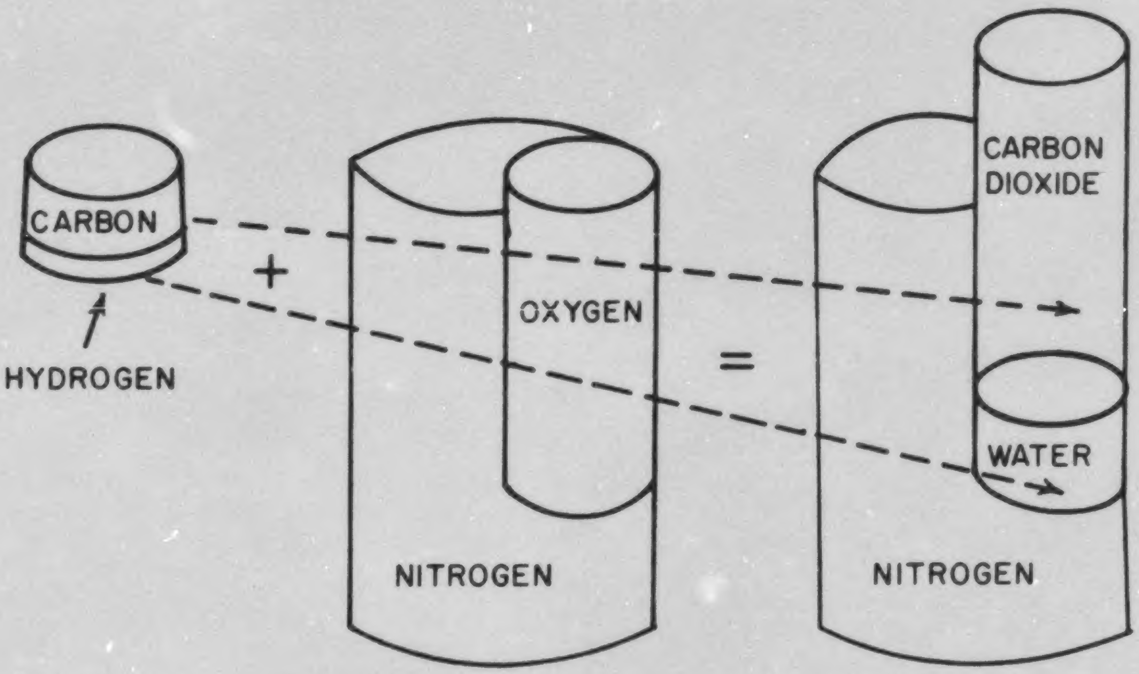
$$2H_2 + O_2 \longrightarrow 2H_2O + \text{HEAT}$$

$$\boxed{S} + \boxed{O_2} \longrightarrow \boxed{SO_2}$$

$$S + O_2 \longrightarrow SO_2 + \text{HEAT}$$

COMBUSTION EQUATIONS

Fig. VIII A 1 1


CARBON
HYDROGEN
+
OXYGEN
NITROGEN
=
CARBON DIOXIDE
WATER
NITROGEN

FUEL+AIR = FLUE GAS

Fig. VIII A 1 2

Objectives: Upon completion of this lesson, the student will:

1. Define the types of combustion.
2. Know why it is necessary to be able to control the combustion process.

Information: In order to understand combustion and what we are trying to accomplish when burning fuel, it is necessary to discuss some terminology.

1. Primary air – air that will control the rate of combustion. It is the amount of fuel you can burn.
2. Secondary air – air that will control the combustion efficiency. It controls how well you burn the fuel.
3. Excess air – air that is supplied to the boiler that is extra. It is above the theoretical amount needed.

Combustion may be classified or broken down into three categories:

1. Perfect combustion – burning of all the fuel with only the theoretical amount of air supplied. This can never be achieved in a boiler room. This is only possible in a lab where the combustion process can be carefully controlled.
2. Complete combustion – burning of all the fuel with the proper amount of excess air supplied. This is what we strive for in a boiler room. We want to burn all the fuel so that we do not add pollutants to our already polluted atmosphere.
3. Incomplete combustion – all the fuel is not burned for one reason or another, resulting in the formation of soot and smoke.

It is the operator's responsibility to be thoroughly familiar with his equipment and the combustion process. Many states have passed laws limiting the amount of sulphur contained in fuel oil. This cuts down on the sulphur dioxide that is discharged with the gasses of combustion. By carefully controlling the combustion process we eliminate soot and smoke being discharged by our stack. Fly ash, which is small light particles of ash that would normally be discharged with the combustion gasses, is handled by fly ash precipitators. These precipitators trap and hold it so that it may be disposed of.

Fines are being levied against buildings that do not conform to the Anti-Pollution Laws. It may be against the law to discharge smoke, soot, or fly ash into the atmosphere. The fines can run into hundreds of dollars in many states.

Reference: 1. *Steam Plant Operation*

2. *Air Pollution Manual*

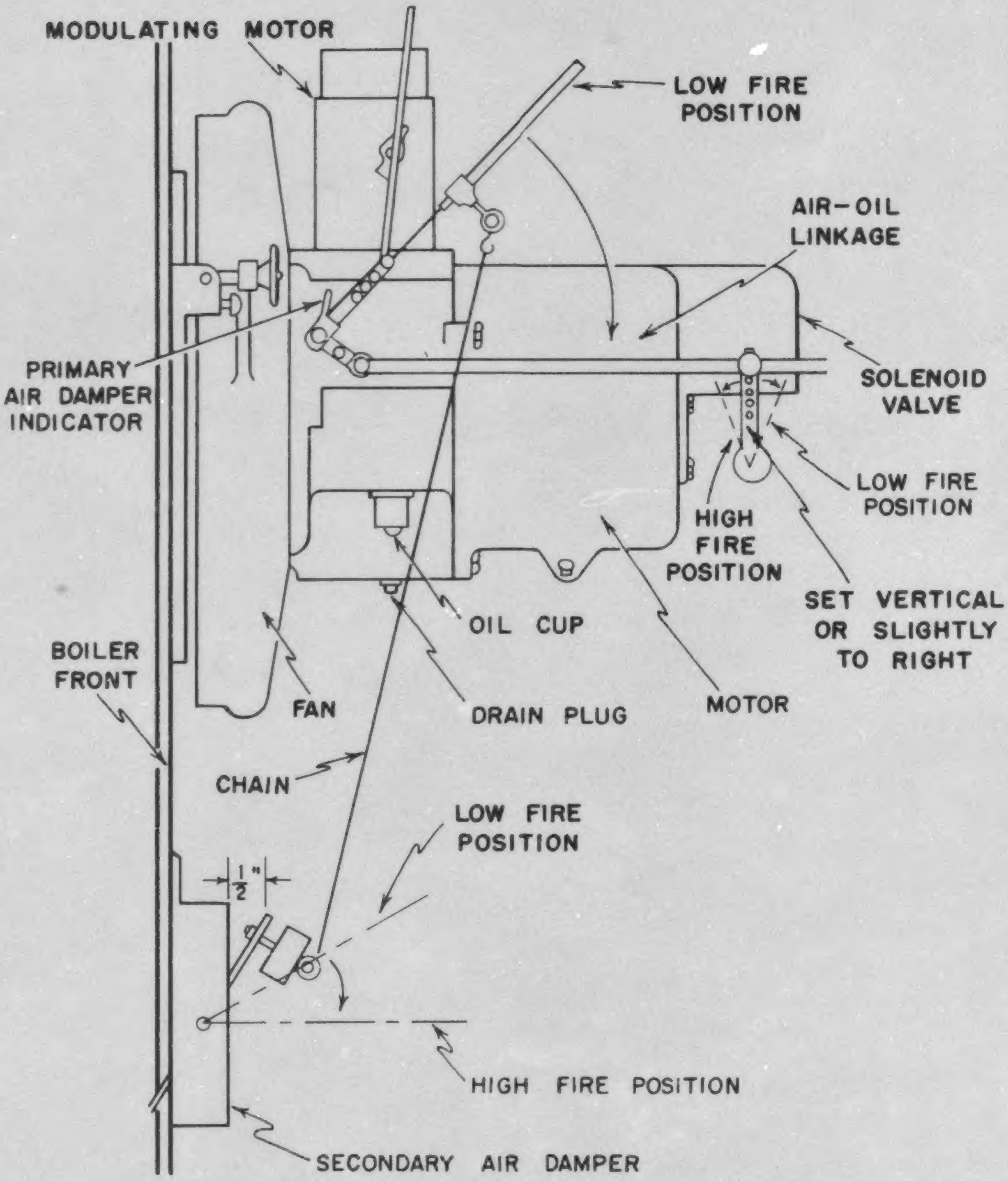
Procedure: After studying the listed reference and information, do the following assignment and be prepared to discuss it in class.

Assignment: 1. Define the following:

    a. primary air
    b. secondary air
    c. excess air
    d. perfect combustion
    e. complete combustion
    f. incomplete combustion

2. Why do you think perfect combustion is not possible in a boiler room?

3. What would result if you were using more excess air than necessary?


MODULATING MOTOR
LOW FIRE POSITION
AIR-OIL LINKAGE
SOLENOID VALVE
PRIMARY AIR DAMPER INDICATOR
LOW FIRE POSITION
HIGH FIRE POSITION
SET VERTICAL OR SLIGHTLY TO RIGHT
OIL CUP
BOILER FRONT
FAN
DRAIN PLUG
MOTOR
CHAIN
LOW FIRE POSITION
1/2"
HIGH FIRE POSITION
SECONDARY AIR DAMPER

ROTARY CUP BURNER

Fig. VIII-B-1-1

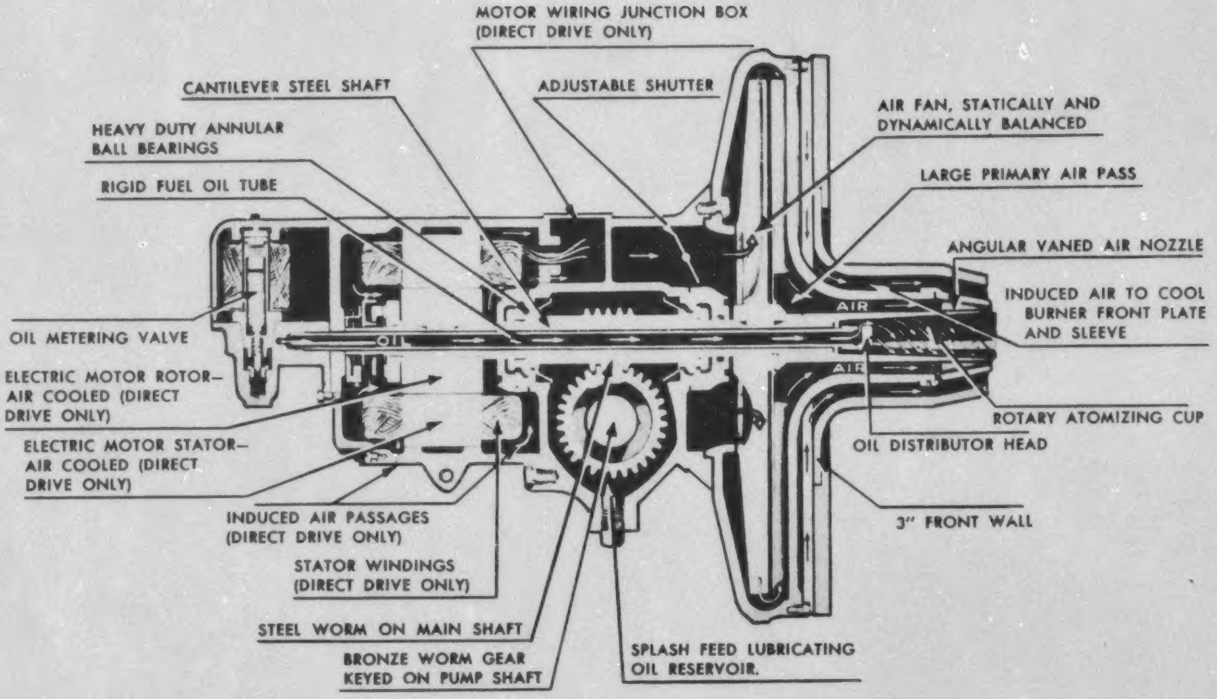
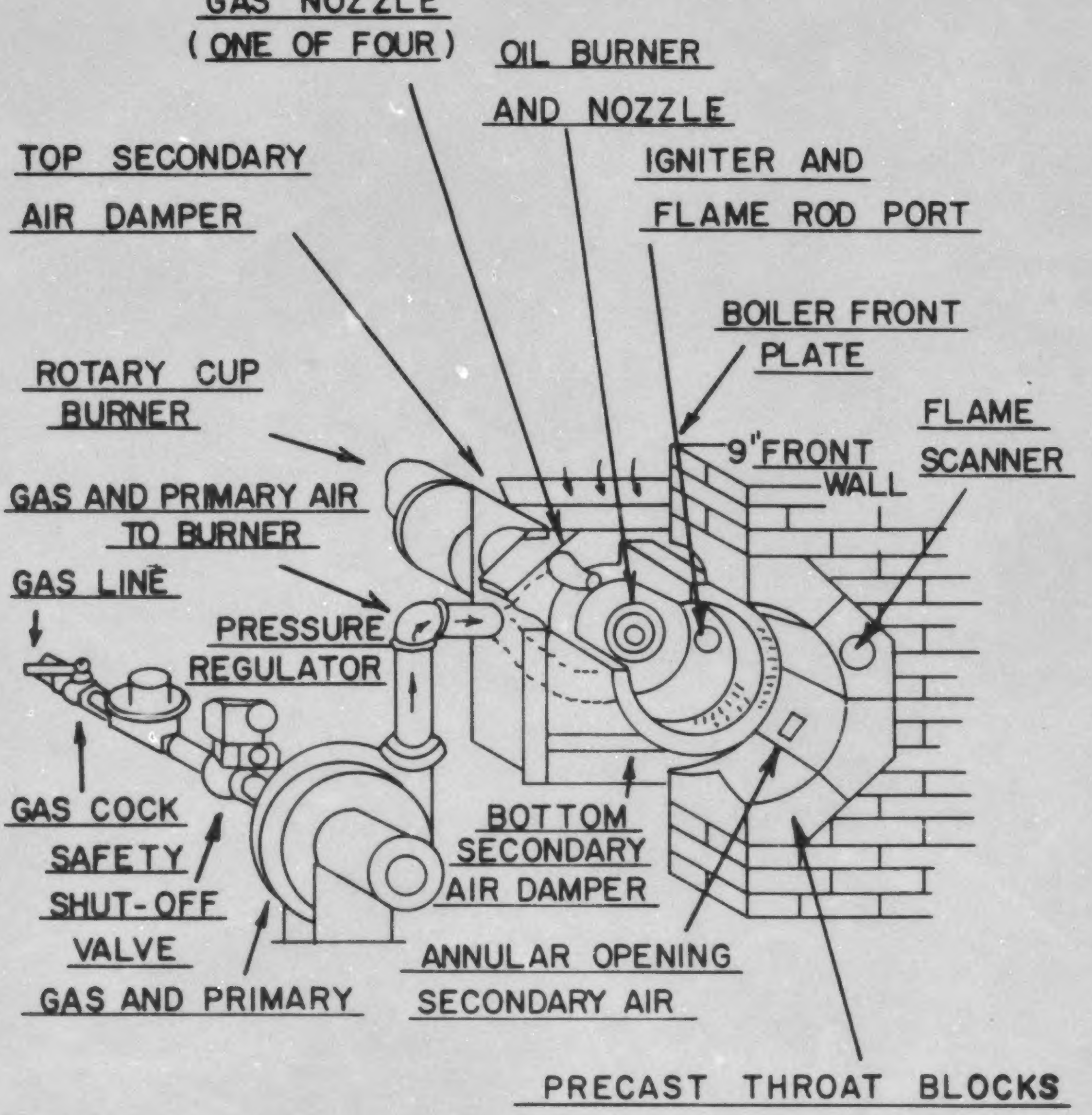
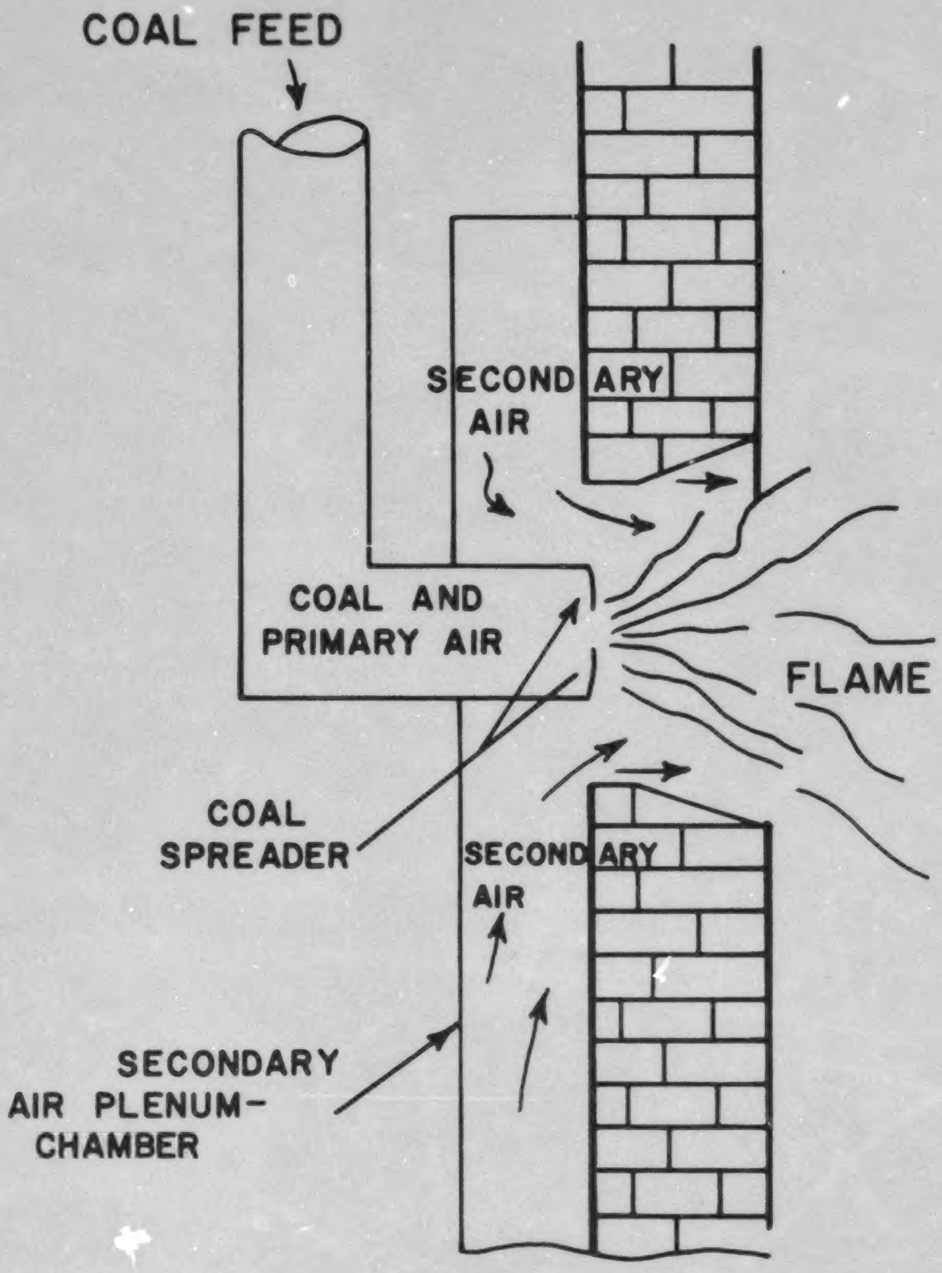

MOTOR WIRING JUNCTION BOX
(DIRECT DRIVE ONLY)
CANTILEVER STEEL SHAFT
ADJUSTABLE SHUTTER
AIR FAN, STATICALLY AND
DYNAMICALLY BALANCED
HEAVY DUTY ANNULAR
BALL BEARINGS
LARGE PRIMARY AIR PASS
RIGID FUEL OIL TUBE
ANGULAR VANED AIR NOZZLE
INDUCED AIR TO COOL
BURNER FRONT PLATE
AND SLEEVE
AIR
OIL
AIR
OIL METERING VALVE
ELECTRIC MOTOR ROTOR–
AIR COOLED (DIRECT
DRIVE ONLY)
ROTARY ATOMIZING CUP
OIL DISTRIBUTOR HEAD
ELECTRIC MOTOR STATOR–
AIR COOLED (DIRECT
DRIVE ONLY)
INDUCED AIR PASSAGES
(DIRECT DRIVE ONLY)
3" FRONT WALL
STATOR WINDINGS
(DIRECT DRIVE ONLY)
STEEL WORM ON MAIN SHAFT
SPLASH FEED LUBRICATING
OIL RESERVOIR.
BRONZE WORM GEAR
KEYED ON PUMP SHAFT

Fig. VIII-B-1-2


GAS NOZZLE (ONE OF FOUR)
OIL BURNER AND NOZZLE
TOP SECONDARY AIR DAMPER
IGNITER AND FLAME ROD PORT
BOILER FRONT PLATE
ROTARY CUP BURNER
FLAME SCANNER
9" FRONT WALL
GAS AND PRIMARY AIR TO BURNER
GAS LINE
PRESSURE REGULATOR
GAS COCK
SAFETY SHUT-OFF VALVE
BOTTOM SECONDARY AIR DAMPER
GAS AND PRIMARY
ANNULAR OPENING SECONDARY AIR
PRECAST THROAT BLOCKS

SCHEMATIC VIEW COMBINATION GAS AND OIL BURNER FROM INSIDE FURNACE

Fig. VIII-B-1-3


COAL FEED
SECONDARY AIR
COAL AND PRIMARY AIR
FLAME
COAL SPREADER
SECONDARY AIR
SECONDARY AIR PLENUM-CHAMBER

PULVERIZED COAL BURNER SHOWING PRIMARY AND SECONDARY AIR

Fig. VIII-B-1-4

Objectives: Upon completion of this lesson, the student will:

1. Know the combustion process.
2. Know what is needed in order to arrive at complete combustion.

Information: In assignment VIII-B-1 on types of combustion, we discussed:

a. primary air
b. secondary air
c. excess air
d. perfect combustion
e. complete combustion
f. incomplete combustion

We also said that our goal is complete combustion, which is the burning of all the fuel with the proper amount of excess air. In order to accomplish this we need four things. You can best remember them by the word M.A.T.T.

M – Proper *mixture* of air and fuel. The ratio of air and fuel must be controlled at all firing rates. High fire when you burn the maximum amounts of oil would require more air than when when burner is in low fire.

A – Proper *atomization* of fuel. This breaks up fuel into small particles so that it can come in more intimate contact with the air. It improves combustion.

T – Proper *temperature*. Air, fuel, and zone temperature must be maintained in order to achieve complete combustion.

T – *Time* to complete combustion. The combustion process must be completed before the gasses of combustion come in contact with the heating surface.
Note: You should remember that heating surface is where there is water on one side and gasses of combustion on the other.

If the gasses of combustion come in contact with the heating surface before combustion is complete, they will cool, causing the formation of soot and smoke.

We spoke about air needed for combustion of fuel. It might be well to mention that it is the oxygen in the air that is needed. Air is made up of approximately 20% oxygen and 80% nitrogen. Nitrogen does not enter the combustion process.

Reference: *Steam Plant Operation*

Procedure: After studying the reference and information, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What is meant by complete combustion?
2. Discuss what is meant by M.A.T.T.
3. What will result if the gasses of combustion come in contact with the heating surface before the combustion process is completed?
4. Why must the oil be atomized?
5. What is the chemical composition of air, and what happens to these chemical elements during the combustion process?

Objectives: Upon completion of this lesson, the student will:

1. Understand the formula for finding the theoretical amounts of air needed per pound of fuel.
2. Be able to find the theoretical pounds of air required per pound of fuel.
3. Be able to find the theoretical pounds of oxygen required per pound of fuel.

Information: In order for combustion to take place, air must be supplied in quantity. Only oxygen will enter into chemical combination with fuel. (See VIII-A-1). In order to supply one pound of oxygen to a furnace, it is necessary to supply 4.32 pounds of air. The theoretical amount of air is the minimum amount of air that is needed to burn 1 pound of fuel completely. This means burning all the carbon to CO_2, the hydrogen to H_2O, and all the sulphur to SO_2. Burning 1 pound of carbon completely requires 11.53 pounds of air. To burn 1 pound of hydrogen minus 1/8 the oxygen (found in the fuel) requires 34.56 pounds of air, and to completely burn 1 pound of sulphur requires 4.32 pounds of air.

We can then establish the following formula:

$$\#\text{air}/\#\text{fuel} = 11.53C + 34.56\left(H - \frac{\text{Oxygen}}{8}\right) + 4.32S$$

In order to use the above formula it is necessary to know the chemical composition of the fuel which is basically: N O C A S H.

N – Nitrogen
O – Oxygen
C – Carbon
A – Ash
S – Sulphur
H – Hydrogen

The % of each element found in the fuel will be given in the ultimate analysis of the fuel.

Note: This will only be the theoretical amount of air required. It will be necessary to provide 15% to 20% excess air to have complete combustion.

Example: The ultimate analysis of a fuel is as follows:

carbon	70%	oxygen	8%
hydrogen	7%	sulphur	2%
nitrogen	5%	ash	8%

Find: a. pounds of air/pound of fuel
b. pounds of oxygen

$$\#air/\#fuel = 11.53\,C + 34.56\left(H - \frac{Oxygen}{8}\right) + 4.32\,S$$

$$= 11.53 \times .7 + 34.56\left(.07 - \frac{.08}{8}\right) + 4.32 \times .02$$

$$= 8.071 + .02419 + .0864$$

$$= 8.182 \text{ pounds of air}$$

4.32# air = 1# oxygen

$$\frac{8.182}{4.32} = 1.89\# \text{ of oxygen}$$

Procedure: After having read the information and studied the sample problem,do the following assignment.

Assignment: 1. The ultimate analysis of a fuel is as follows:

carbon	65%	oxygen	11%
hydrogen	6%	sulphur	4%
nitrogen	2%	ash	12%

Find: a. #'s of air/#'s fuel
b. #'s of oxygen

2. The ultimate analysis of a fuel is as follows:

carbon	61.5%	oxygen	6.2%
hydrogen	6.8%	sulphur	5.6%
nitrogen	3.4%	ash	1.1%

Find: a. #'s of air/#'s of fuel
b. #'s of oxygen.

3. The ultimate analysis of a fuel is as follows:

carbon	85%	oxygen	5%
hydrogen	5%	sulphur	1%
nitrogen	2%	ash	2%

Find: a. #'s of air/#'s fuel
b. #'s of oxygen

4. The ultimate analysis of a fuel is as follows:

carbon	88.86%	oxygen	1.95%
hydrogen	2.04%	sulphur	.35%
nitrogen	.9%	ash	5.9%

Find: a. #'s of air/#'s of fuel
b. #'s of oxygen

5. A plant is using a fuel that requires 14.5 pounds of air per pound of fuel. It burns 780 pounds of fuel per hour.

   Find: a. #'s of air needed per hour.
   b. #'s of oxygen.

6. If 20% excess air is needed in the above problem, what are the actual air and oxygen requirements?

Mechanical Atomizing Burner

Assignment IX-A-1

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with the mechanical atomizing burner.
2. Know the parts of the burner.
3. Know the operation of the burner.

Information: Mechanical atomizing burners are sometimes called high pressure atomizing burners. They atomize the fuel oil without the use of steam or air. Oil is pumped to the burner at a pressure of not less than 100 p.s.i. A nozzle consisting of tangential slots, whirl chamber, and orifice spray the oil out into the combustion chamber in a fine mist or spray.

A basic mechanical atomizing burner unit consists of a fan and housing, an electric motor, a pump, a strainer, a pressure regulating valve, a nozzle, and a means of igniting the atomized oil.

The following is a list of parts and their purpose:

a. Motor – used to drive fan and oil pump.

b. Fan – squirrel cage type coupled to motor shaft and supplies air needed for combustion.

c. Strainer – located in fuel oil line before pump to protect it from foreign particles and sediment in the fuel oil.

d. Fuel oil pump – rotary positive displacement pumps suppling oil at a minumum pressure of 100 p.s.i. to the burner nozzle.

e. Pressure regulator valve – consists of a spring loaded diaphragm, bellows, or a piston which controls flow of oil to the nozzle and diverts the excess oil back to the fuel oil tank.

f. Ignition transformer – provides high voltage A.C. current used to give a spark for igniting the oil or pilot.

g. Nozzles – used to atomize the fuel oil and must be accurately made.

h. Air diffuser – the air pattern of a mechanical atomizing burner is important and is determined by the design of the diffuser.

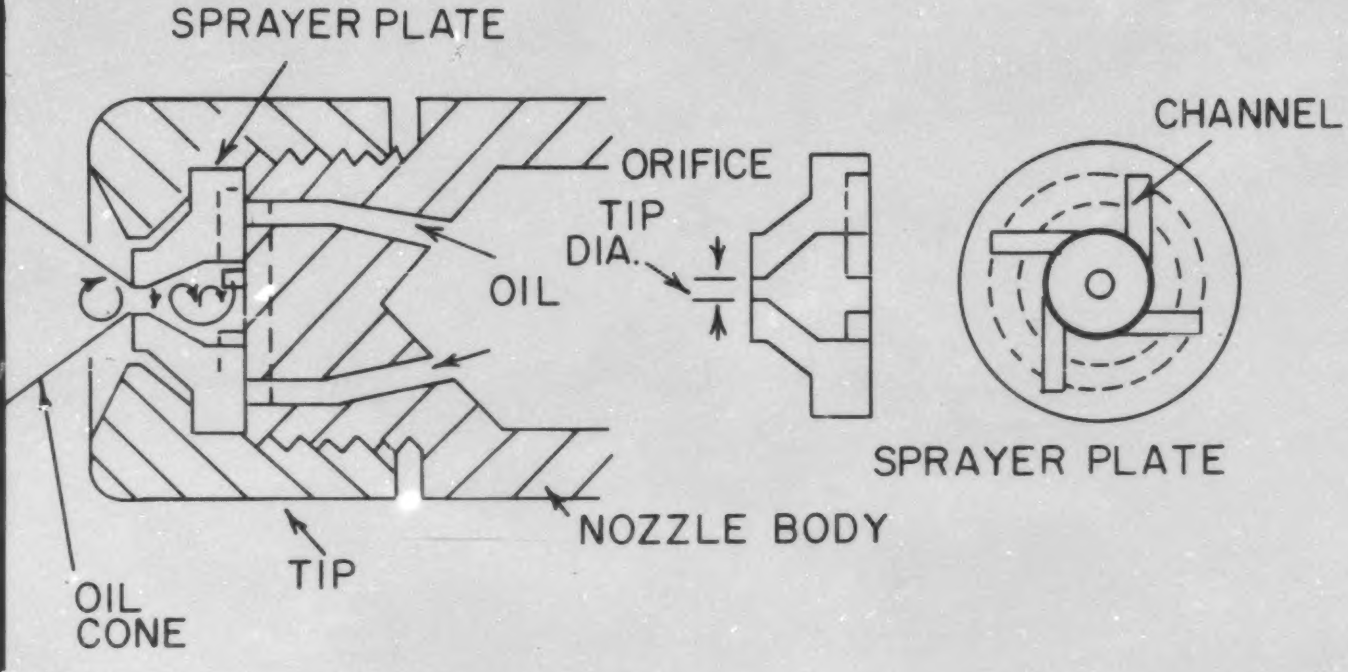
References:

1. *Steam Plant Operation*
2. *Handbook of Oil Burners*
3. *B & W Burners*
4. *Steam Boilers*

Procedure: After studying the listed references and information, do the following assignment and be prepared to discuss it in class.

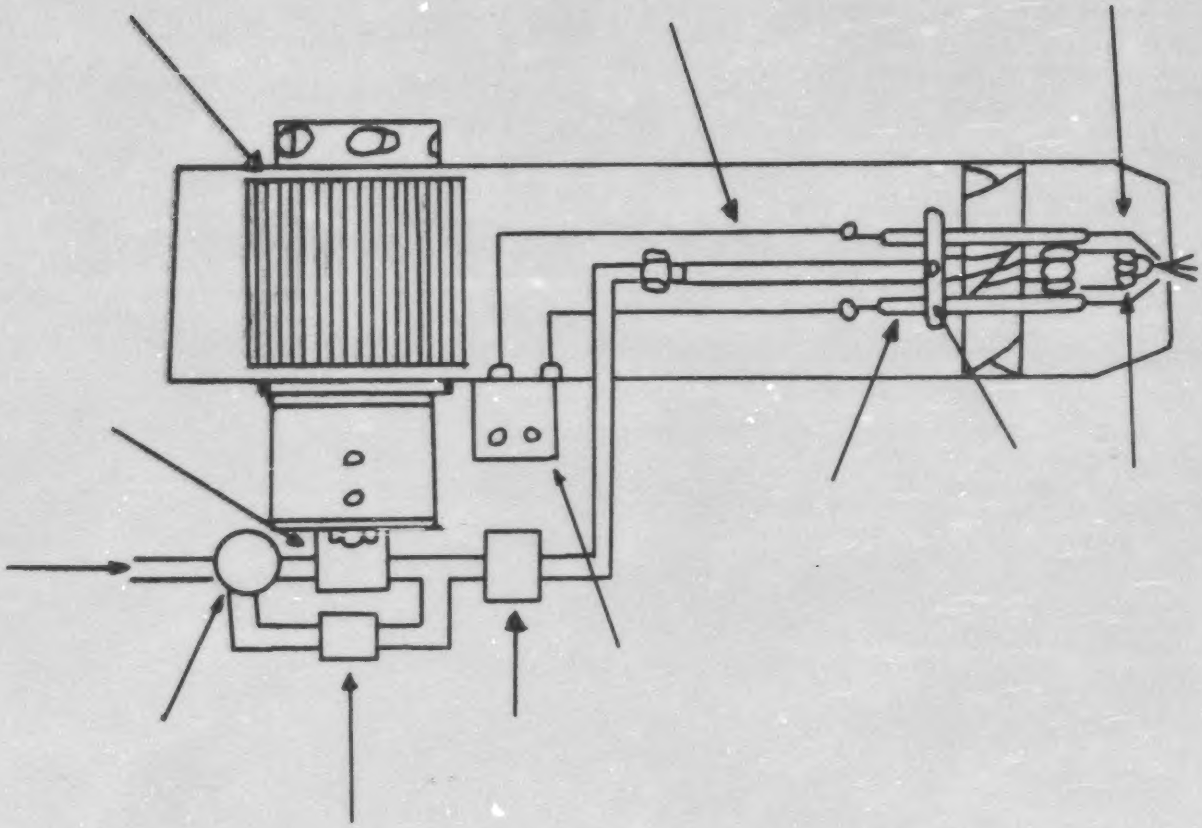
Assignment:

1. Explain the principle of operation of a mechanical atomizing burner.
2. Name the parts of a burner and explain what they are used for.
3. How can the amount of oil be controlled to the burner nozzle? What happens to the excess oil?
4. Explain how the air is supplied to the burner nozzle and mixed with the oil.


SPRAYER PLATE
CHANNEL
ORIFICE
TIP
DIA.
OIL
SPRAYER PLATE
NOZZLE BODY
TIP
OIL
CONE

SPRAYER-PLATE ATOMIZER

Fig. IX-A-1-1



Pressure Atomizing Burner

Fig. IX-A-1-2

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of an air atomizing burner.
2. Know the parts of the air atomizing burner.
3. Know the operation of the air atomizing burner.

Information: The automatically fired air atomizing burner must control the following:

1. atomizing of fuel oil
2. flow of fuel oil
3. ignition of air-fuel mixture
4. correct air to oil mixture (ratio)
5. correct amount of air for atomizing fuel oil

The word atomize means to change a liquid into a fine spray. This is accomplished by the use of air under pressure forcing the oil through a nozzle assembly. Breaking the oil up into a fine mist or spray allows the air to come in closer contact with the oil, which results in clean complete combustion.

The burner controls the flow of fuel oil to the nozzle assembly by the use of an oil solenoid valve.

Ignition of the air-fuel mixture is accomplished by a high voltage electric spark igniting a gas pilot. The pilot is programed in the burner cycle to ignite the main burner flame at the proper time. Additional air (secondary air) is allowed to mix with the burning fuel by using an air shutter or damper. The amount of secondary air depends on the firing rate of the burner.

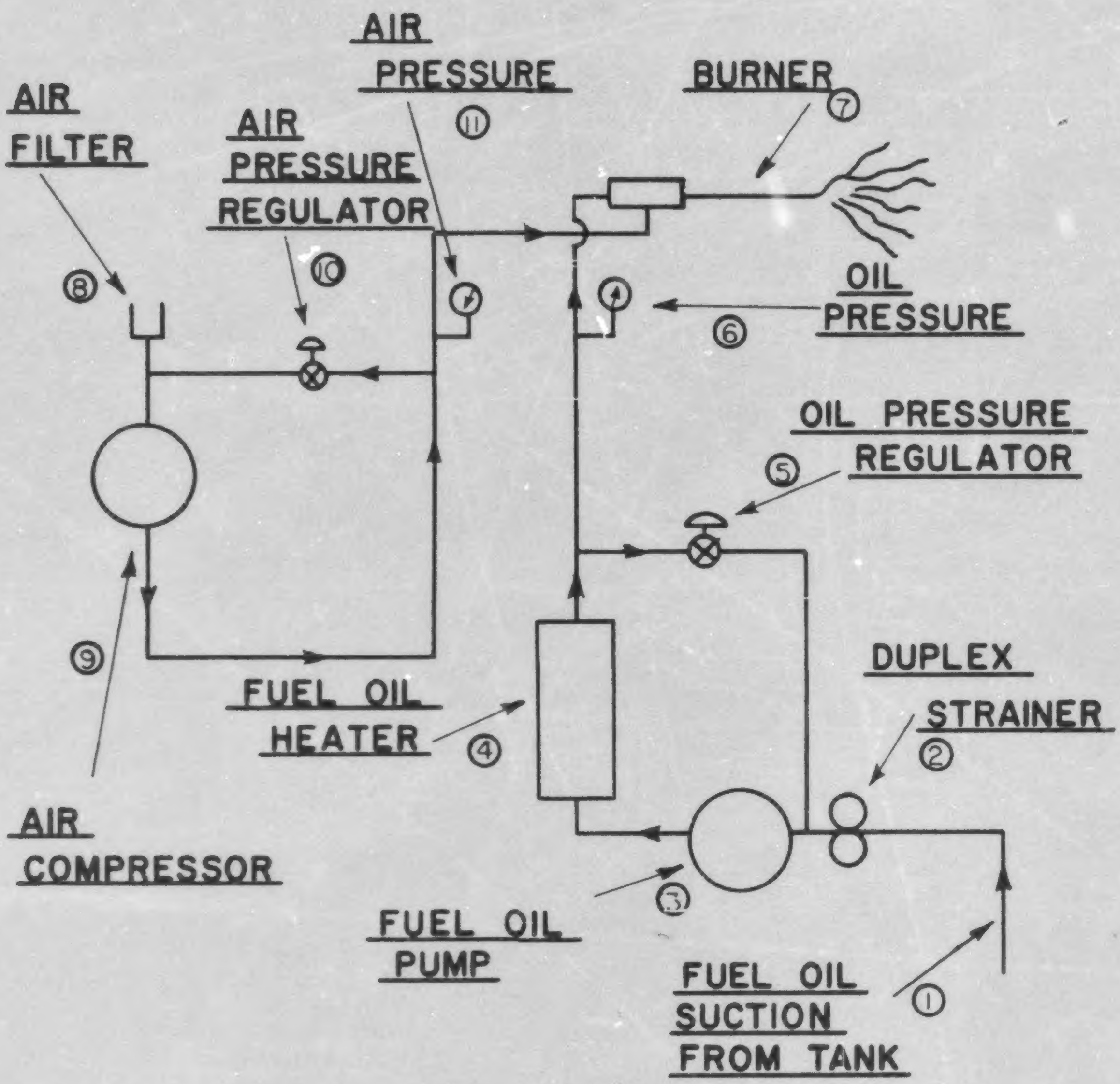
Atomizing air is supplied by an oil-air pump at the burner nozzle assembly at the correct pressure.

Reference: Manufacturer's data sheets and catalogs

Procedure: After studying the listed reference, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Name the parts of the air atomizing burner and explain their purpose.
2. Describe how the burner nozzle assembly atomizes the fuel oil.
3. Explain the complete burner cycle.


AIR PRESSURE
⑪
BURNER
⑦
AIR FILTER
AIR PRESSURE REGULATOR
⑩
⑧
OIL PRESSURE
⑥
OIL PRESSURE REGULATOR
⑤
DUPLEX STRAINER
②
⑨
FUEL OIL HEATER
④
AIR COMPRESSOR
③
FUEL OIL PUMP
FUEL OIL SUCTION FROM TANK
①

SCHEMATIC AIR ATOMIZING BURNER

Fig. IX-A-2-1

Rotary Cup Oil Burner — Assignment IX-A-3

Objectives: Upon completion of this lesson, the student will:

1. Understand the purpose of the rotary cup oil burner.
2. Know the parts of the rotary cup oil burner.
3. Know the operation of the rotary cup oil burner.

Information: The horizontal rotary oil burner has always been a popular burner because of its versatility. It can burn a wide range of grades of oil successfully and is made in a variety of sizes. It is used in power plants, large buildings and process plants.

The horizontal rotary burner consists of an atomizing or spinning cup, a blower to supply air for combustion (primary air), an air nozzle to mix the air and oil, a means of driving the atomizing cup and blower, and a means for delivering oil to the atomizing cup. The atomizing cup is rotated usually at a speed of 3450 rpm or higher. The oil spreads over the inner surface of the cup and is eventually thrown off the periphery by centrifugal force. At this point, the air supplied by the blower is directed into the oil spray by the air nozzle. This is not enough air to complete combustion, so it is necessary to admit secondary air to the combustion chamber.

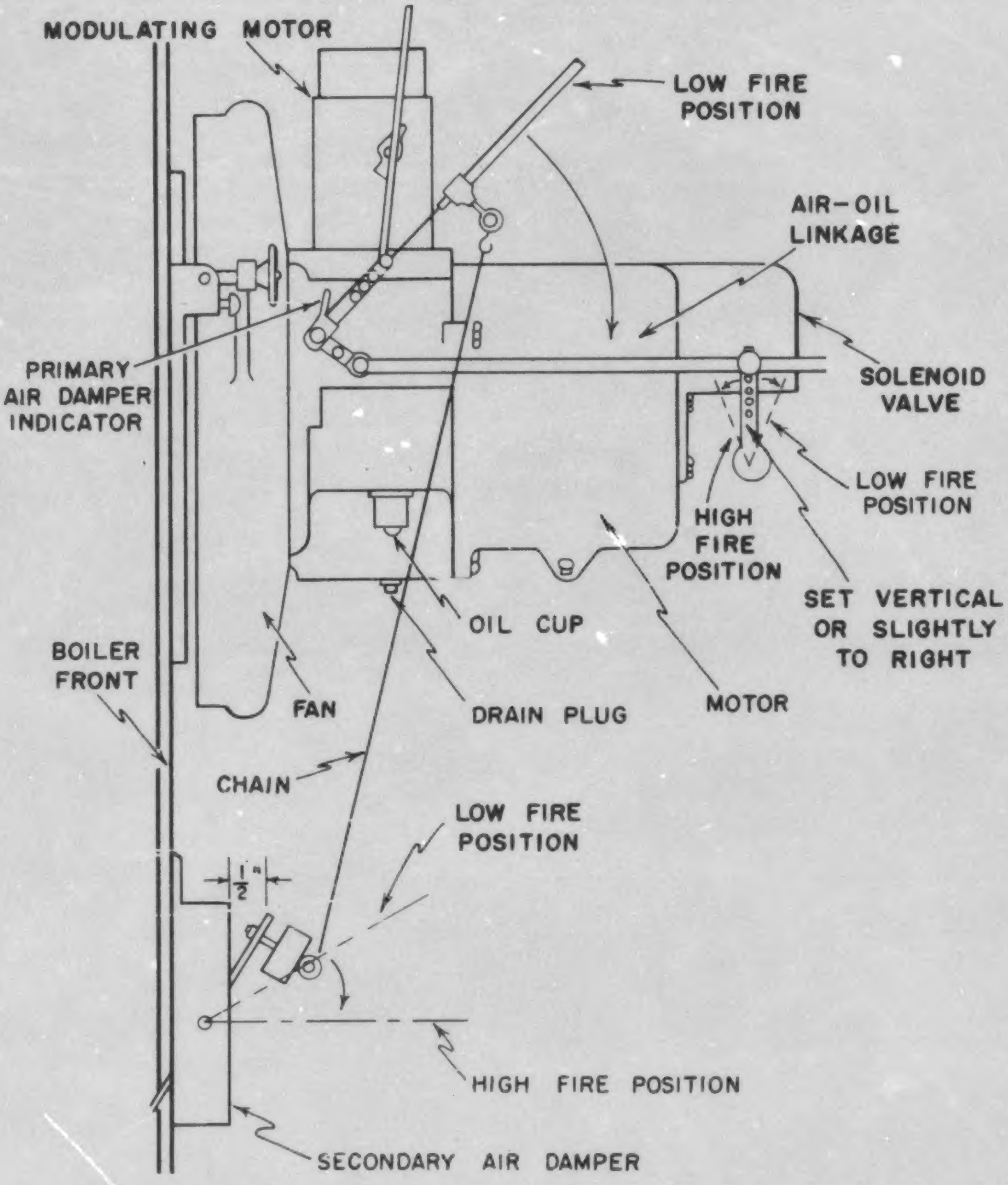
Reference:

1. *Steam Plant Operation*
2. Manufacturers' data sheets and catalogs
3. *Domestic and Commercial Oil Burners*, Burkhardt, McGraw Hill

Procedure: Study the information and listed references; do the following assignment and be prepared to discuss it in class.

Assignment:

1. How is oil atomized in a rotary cup burner?
2. How is oil supplied to the rotary cup?
3. How is primary air supplied to the burner?
4. What is the purpose of primary air in the rotary cup burner?
5. Does the condition of the atomizing cup affect atomization? Explain.


MODULATING MOTOR
LOW FIRE POSITION
AIR-OIL LINKAGE
SOLENOID VALVE
PRIMARY AIR DAMPER INDICATOR
LOW FIRE POSITION
HIGH FIRE POSITION
SET VERTICAL OR SLIGHTLY TO RIGHT
OIL CUP
BOILER FRONT
FAN
DRAIN PLUG
MOTOR
CHAIN
LOW FIRE POSITION
1/2"
HIGH FIRE POSITION
SECONDARY AIR DAMPER

ROTARY CUP BURNER

Fig. IX-A-3-1

Objectives: Upon completion of this lesson, the student will:

1. Know the low-pressure gas burner system.
2. Know the high-pressure gas burner system.
3. Know the color code for gas lines.
4. Know and understand the controls in the high and low pressure gas burner systems.

Information: Natural and manufactured gas have become popular in industry because of their high combustion efficiency and the ease with which they can be burned. The cost is comparable to other fuels.

The pressure of the gas available plays an important part in the type of system you have in your plant. To operate the boiler room safely and to help identify the gas system, many boiler rooms will have the gas lines painted yellow with red stripes.

The first system we will discuss will be a low-pressure gas system. In this system the gas supplied at the burner is reduced to 0 (zero) pounds pressure. The gas and primary air mix together outside the combustion chamber and are forced along to the nozzle by a blower. Using sketch IX-B-1-1 we can trace the system: The gas line (1) is fitted with a gas cock (2) which allows the fireman to close the gas to the system when making repairs. The solenoid valve (3) controls gas to the pilot (4). The manual reset valve (5) is an electric valve that cannot be opened until the gas pilot is lighted. The pressure reducing governor (6) reduces the pressure of the gas to zero pounds pressure. The small line just before the pressure reducing governor goes to the vaporstat (7). The vaporstat is a switch which is turned on by the gas pressure in the line or turned off when there is no pressure. The main gas solenoid valve (8) will open at the proper time allowing gas to be drawn down to the mixjecter (9). The forced draft blower (10) will send air through the butterfly valve (11). The air passes through a venturi (12) and draws the gas with it to the mixing chamber (13).

The block and holder (14) is mounted on the boiler front and as the gas and air mixture passes through the cage, it is ignited by the pilot light (4). The cage has an adjustable ring (15) that controls the secondary air that enters to complete combustion. A gas cock (16) controls the gas flow to the pilot.

The high-pressure gas burner system supplies gas at a set pressure to the burner, where it mixes with the air on the inside of the burner register. Using the sketch IX-B-1-3, trace the high-pressure system.

The gas line (1) is fitted with a pressure gage (2) and a manually operated shut-off valve (3). A gas pressure regulator (4) controls the desired set pressure at the burner. The electrically operated solenoid valve (5) is used as an automatic shut-off gas valve. A gas control flow valve (6) gradually allows the gas to flow to the burner at start-up. A gas volume control valve (butterfly valve) (7) controls the volume of gas to the burner. A gas pilot line (8) supplies gas to the gas pilot regulator (9), a gas pressure gage, (13) and an electrically operated solenoid valve (10). Air is supplied by a forced draft blower (11) and mixes with the gas in the burner register (12) where ignition occurs.

It should be mentioned here that in some boiler installations combination burners are used. These burners are actually two burners in one and are capable of burning gas or oil. The combination burner will be discussed in a later unit.

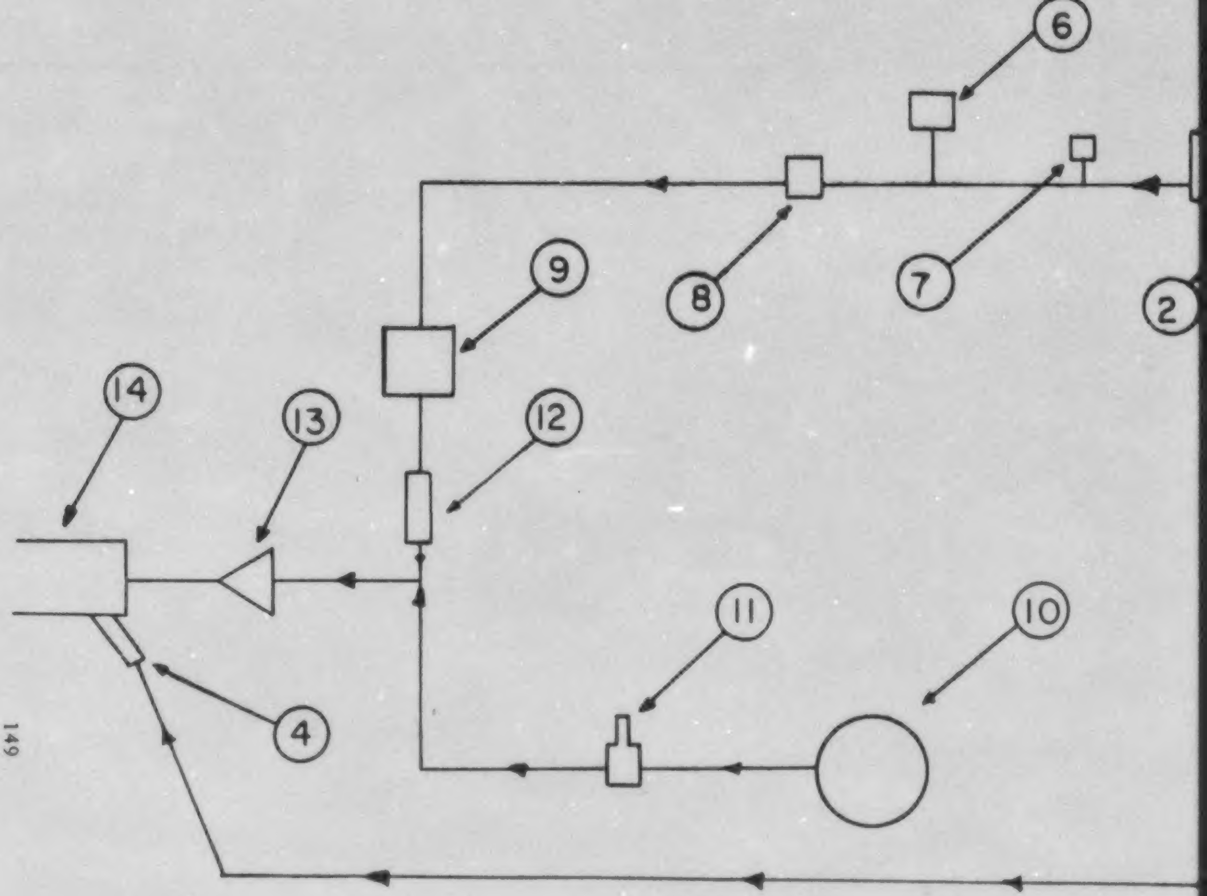
Reference:

1. *Low Pressure Boilers*
2. Manufacturers' data sheets and catalogs

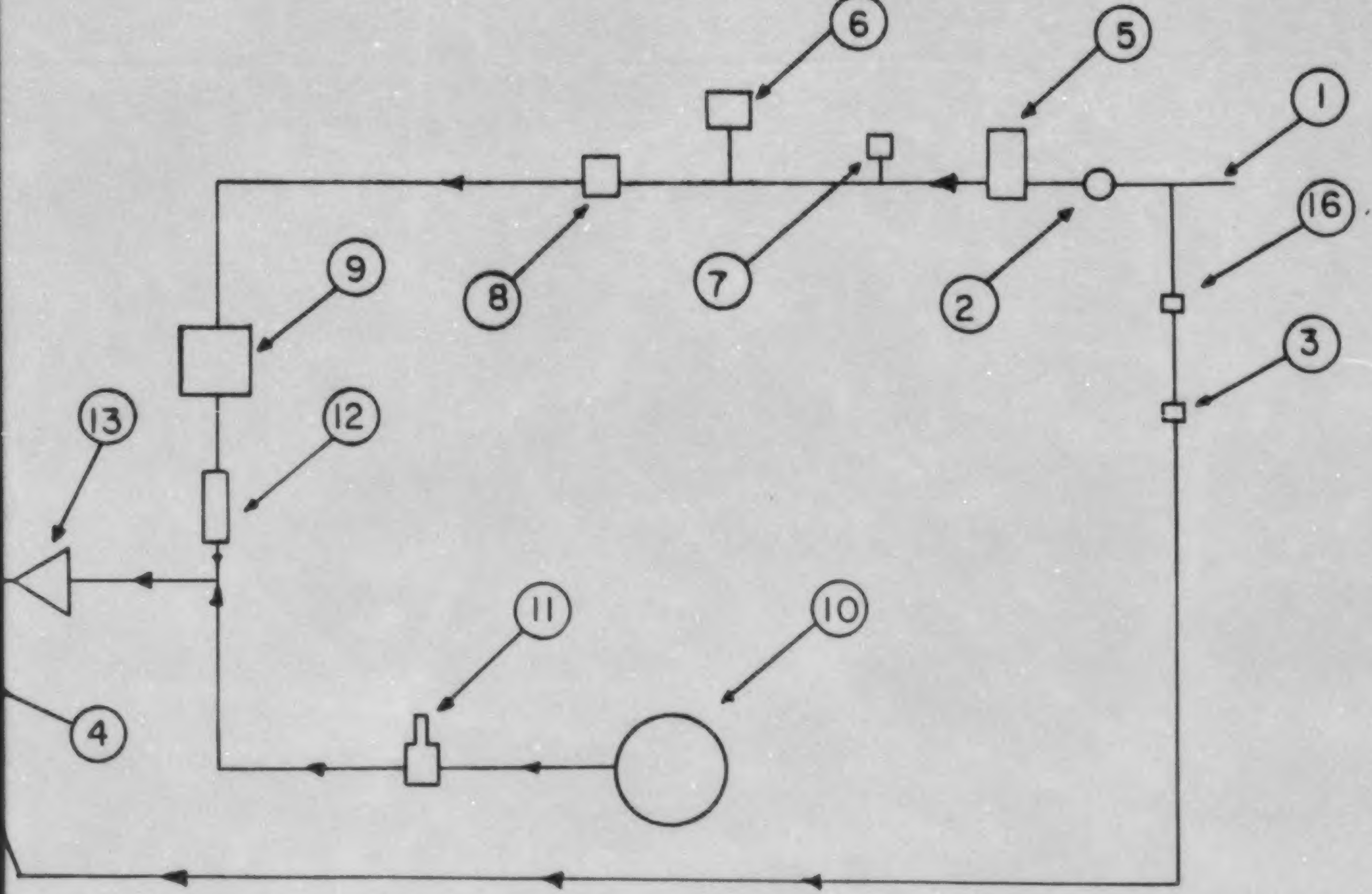
Procedure: After having studied the listed reference and information, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Explain how the low-pressure gas burner system operates.
2. Explain how the high-pressure gas system operates.
3. What is the purpose of color coding the gas pipe and how is it done in the main boiler room of this school?
4. What is the purpose of the manual reset valve?
5. What is the purpose of the vaporstat on the gas line?
6. What is the purpose of the venturi in the gas line?


6
7
8
2
9
14
13
12
11
10
4

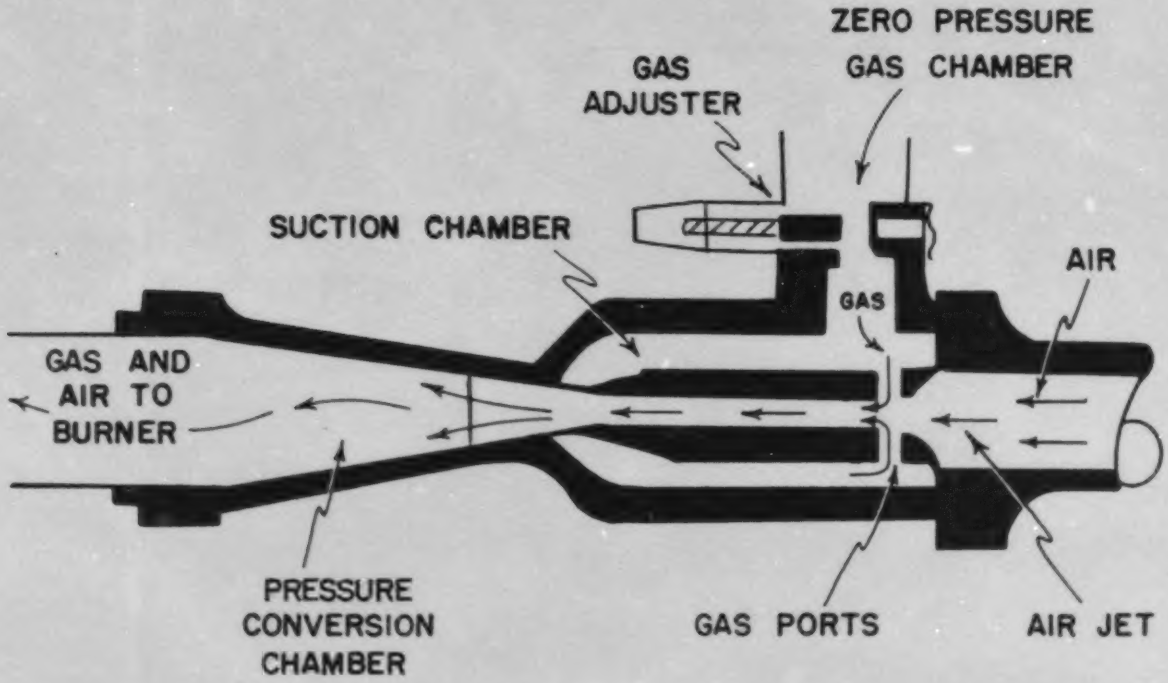
BASIC L.P GAS BURNER SYSTEM


6
5
1
16
9
8
7
2
3
13
12
11
10
4

BASIC L.P GAS BURNER

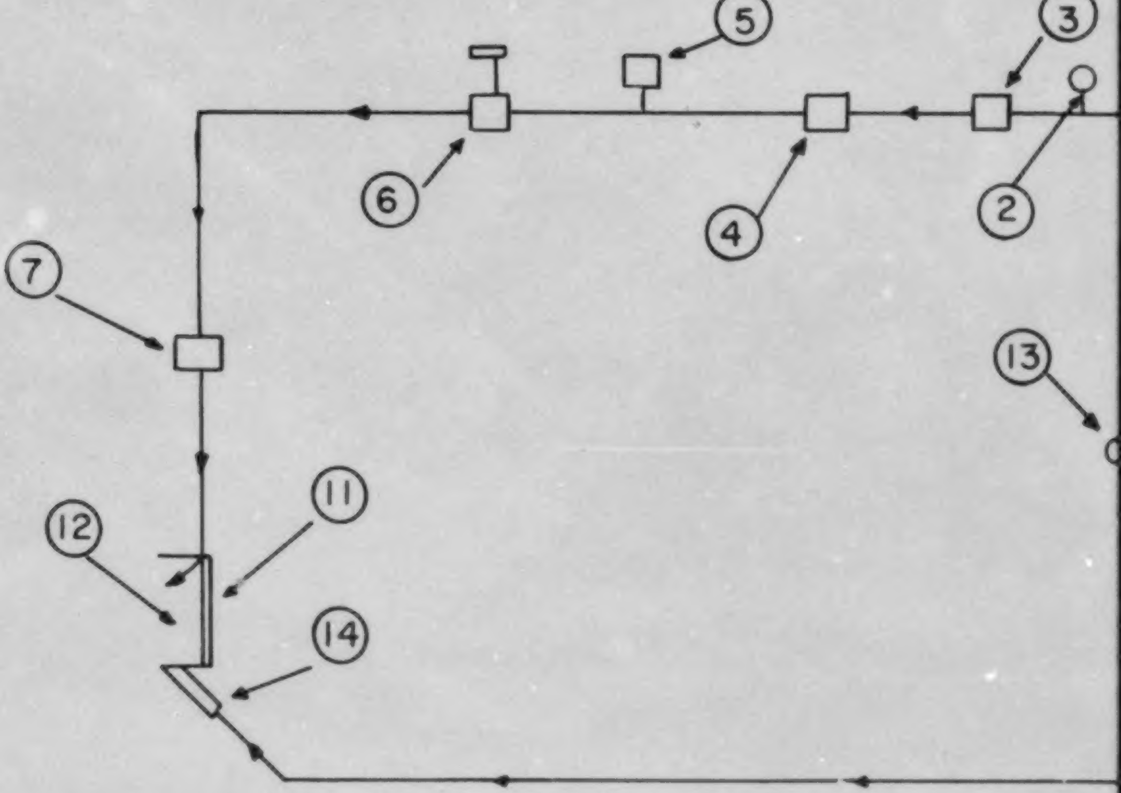
SYSTEM

Fig. IX-B-1-1


ZERO PRESSURE GAS CHAMBER
GAS ADJUSTER
SUCTION CHAMBER
AIR
GAS
GAS AND AIR TO BURNER
PRESSURE CONVERSION CHAMBER
GAS PORTS
AIR JET

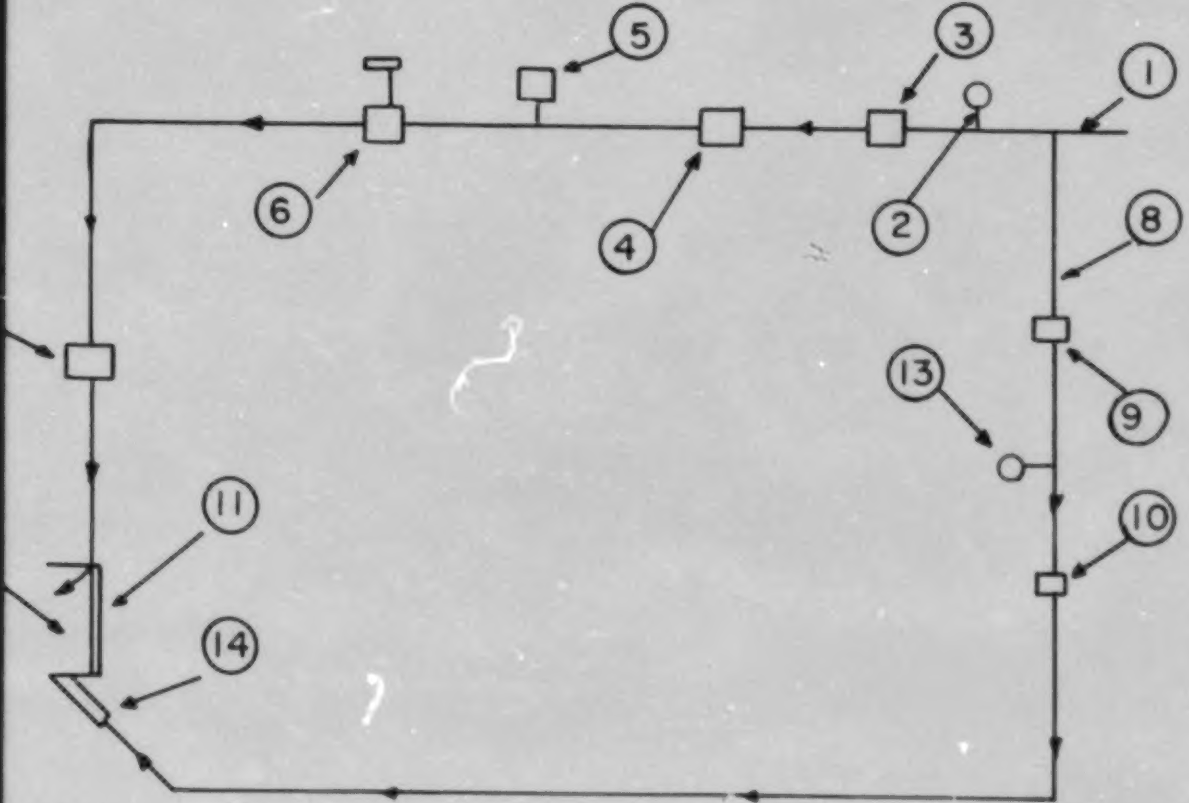
BRYANT FLOMIXER

Fig. IX-B-1-2


5
3
6
4
2
7
13
11
12
14

BASIC H.P. GAS BURNER SYSTEM

Fig. IX-B-


5
3
1
6
4
2
8
13
9
10
11
14

BASIC H.P. GAS BURNER SYSTEM

Fig. IX-B-1-3

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of a combination burner.
2. Be able to identify a combination burner.

Information: Combination gas-oil burners have the advantage over other burners by being able to burn either gas or oil. This is very important when a shut-down due to lack of fuel could be costly. You also have the advantage of burning the fuel that is cheapest at any given time. With the Air Pollution Laws becoming more strict, it may be necessary to burn only gas.

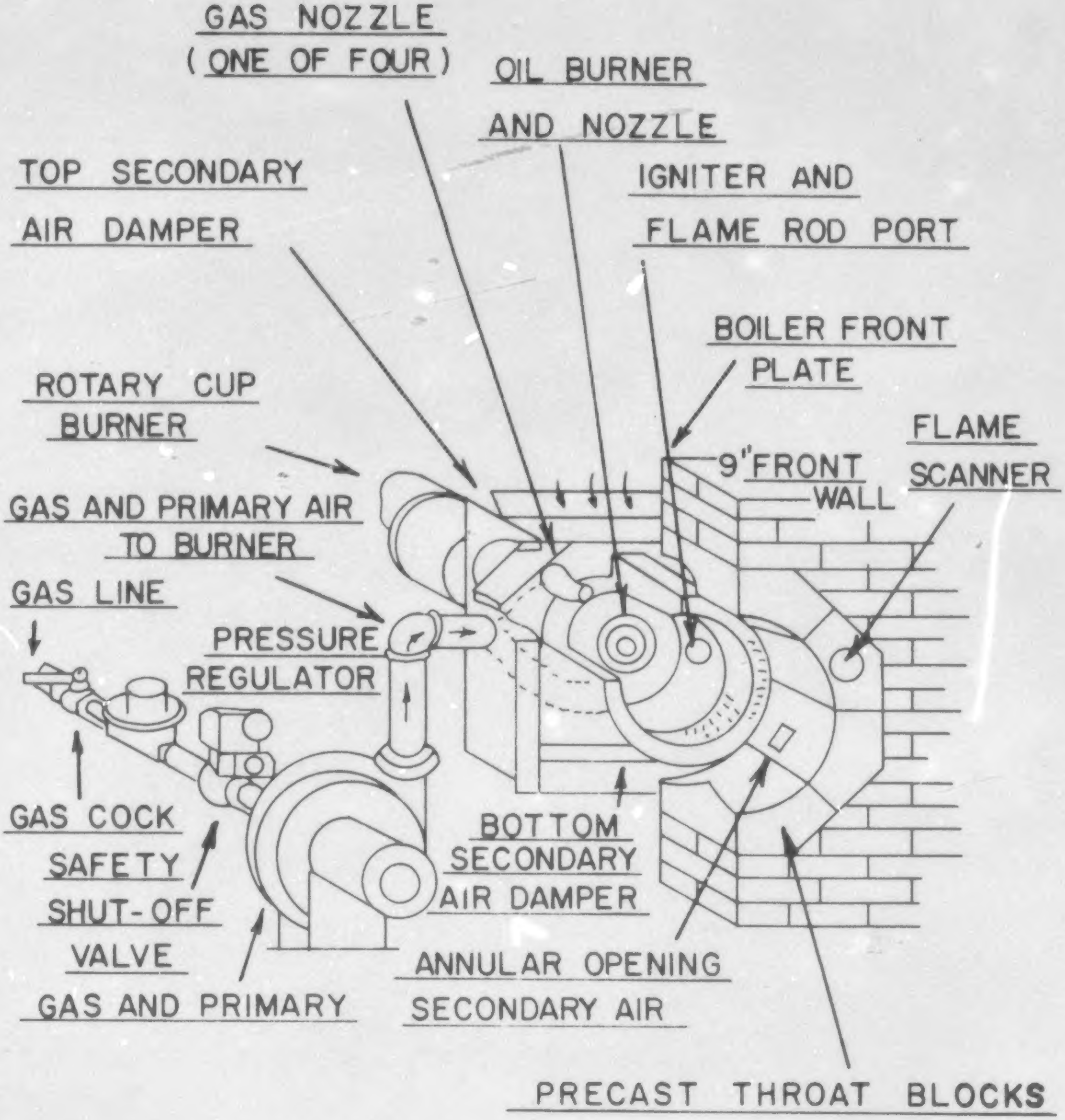
A combination oil-gas burner is basically the same as having an oil burner and a gas burner system connected together at the burner throat (at the front of the furnace). The parts of the system are the same as if they were separate. See sketch IX-C-1-1.

Reference: Manufacturers' data sheets and catalogs

Procedure: After having studied the information and listed references, do the following assignment and be prepared to discuss it in class.

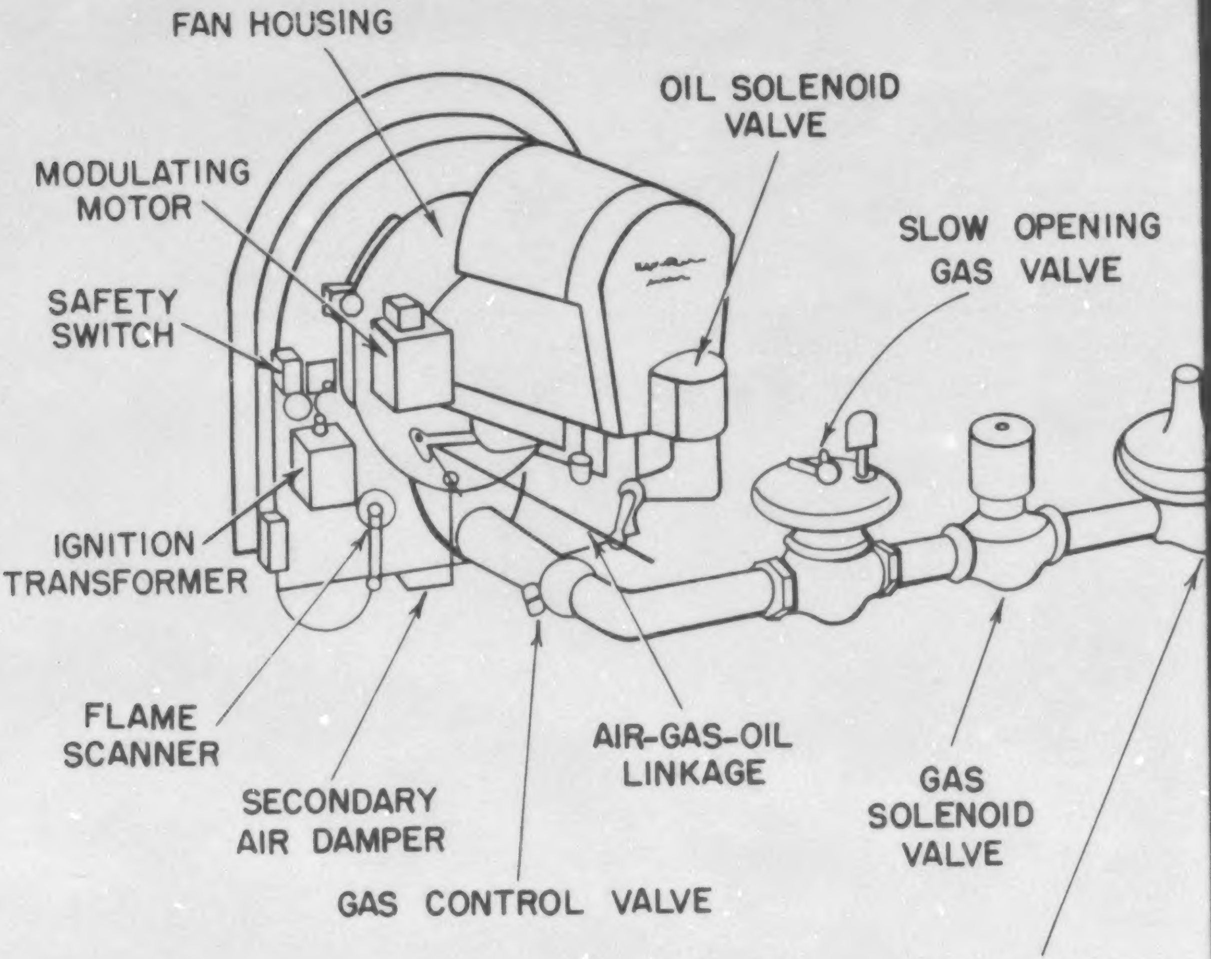
Assignment:

1. State the advantage of a combination over a single fuel burner.
2. Describe a combination gas-oil burner.
3. Why are combination gas-oil burners becoming so popular?


GAS NOZZLE (ONE OF FOUR)
OIL BURNER AND NOZZLE
TOP SECONDARY AIR DAMPER
IGNITER AND FLAME ROD PORT
BOILER FRONT PLATE
ROTARY CUP BURNER
FLAME SCANNER
9" FRONT WALL
GAS AND PRIMARY AIR TO BURNER
GAS LINE
PRESSURE REGULATOR
GAS COCK
SAFETY SHUT-OFF VALVE
BOTTOM SECONDARY AIR DAMPER
GAS AND PRIMARY
ANNULAR OPENING SECONDARY AIR
PRECAST THROAT BLOCKS

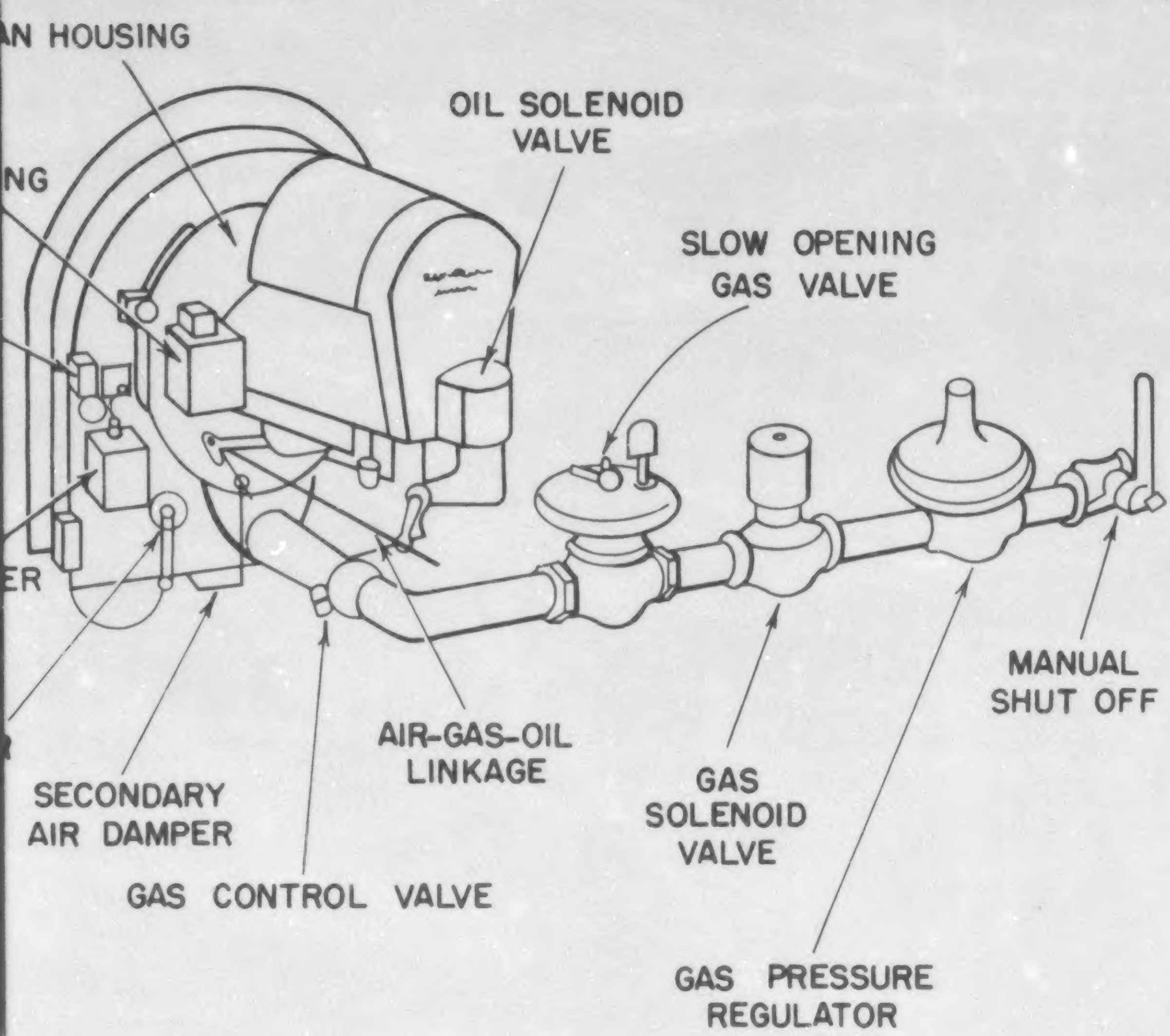
SCHEMATIC VIEW COMBINATION GAS AND OIL BURNER FROM INSIDE FURNACE

Fig. IX-C-1-1


FAN HOUSING
OIL SOLENOID VALVE
MODULATING MOTOR
SLOW OPENING GAS VALVE
SAFETY SWITCH
IGNITION TRANSFORMER
FLAME SCANNER
AIR-GAS-OIL LINKAGE
GAS SOLENOID VALVE
SECONDARY AIR DAMPER
GAS CONTROL VALVE
GAS PRESSURE REGULATOR

COMBINATION GAS-OIL BURNER

Fig.


AN HOUSING
NG
OIL SOLENOID VALVE
SLOW OPENING GAS VALVE
ER
MANUAL SHUT OFF
AIR-GAS-OIL LINKAGE
SECONDARY AIR DAMPER
GAS SOLENOID VALVE
GAS CONTROL VALVE
GAS PRESSURE REGULATOR

COMBINATION GAS-OIL BURNER

Fig. IX-C-1-2

Objectives: Upon completion of this lesson, the student will:

1. Know what is meant by refrigeration.
2. Understand the three basic factors involved in refrigeration.
3. Know the part heat plays in refrigeration.

Information: Man has always tried to control his environment. He wants to be warm in the winter and cool in the summer. In order for us to do an intelligent job of controlling our environment we first must know a little bit about this *thing* we are trying to control. What is this *THING* called? Why it is *HEAT* of course. We want to know how to add heat to a substance to warm us, and how to take heat away from a substance to cool us. Look at this thing called heat and see if we can find out what makes it tick.

First, heat is a form of energy and energy can do work.

Second, all substances are made up of molecules. The molecules move faster as more heat is added to a substance. So we can say that heat is a form of energy due to molecules in motion. Heat will always travel from a warm substance toward a cool substance. Heat may move in three ways:

a. conduction
b. convection
c. radiation

Knowing these facts allows us to make heat do what we want it to do.

The American Society of Refrigerating Engineers defines refrigeration as *The science of providing and maintaining temperatures below that of the surrounding atmosphere.* It has also been defined as the process of removing heat from a substance.

Man has always had a problem of preserving his food – snow, ice and cold water have been used. Ice was cut in the winter and stored for use in the summer. The first artificial ice was produced in the 1820's and the first automatic refrigerator available in the United States was in 1918. This makes the refrigeration industry rather young; and remarkable strides have been made over the past 50 years.

Refrigeration systems may be broken down into five broad classifications:

1. domestic
2. commercial
3. industrial
4. air conditioning
5. marine

The three basic factors involved in refrigeration are:

1. heat exchange
2. control of pressure
3. gas-liquid relationship

Before we go on we should review some basic terminology:

1. B.t.u. – British thermal unit. A measurement of heat. One B.t.u. is the amount of heat necessary to raise the temperature of 1# of water 1° F.
2. Latent heat – hidden heat. It will change the state of a substance but not its temperature.
3. Sensible heat – can be felt and measured with a thermometer. It will change the temperature of a substance but not its state.
4. Latent heat of fusion – B.t.u.'s necessary to change one pound of ice at 32° F. to one pound of water at 32° F.
5. Latent heat of evaporation – B.t.u.'s necessary to change one pound of water at 212° F. to one pound of steam at 212° F.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After having read the information and reference, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Can you explain how heat is transferred?
2. If the latent heat of fusion is removed from 1# of water at 32° F. what would happen?
3. What are the 3 basic factors involved in the refrigeration process?
4. From your instructor's presentation list the B.t.u.'s required:
    a. to change 1# of ice at 32° F. to 1# water at 32° F.
    b. to raise the temperature of 1# water at 32° F. to 1# water at 212° F.
    c. to change 1# of water at 212° F. to 1# steam at 212° F.

Objective: Upon completion of this lesson, the student will understand the theory of operation of a compression system.

Information: There are certain Laws of Refrigeration that will hold true no matter what type of refrigeration system you study.

1. When changing from a liquid state to a gaseous state a fluid absorbs heat.
2. When changing from a gaseous state to a liquid state a fluid gives up heat.
3. If the pressure remains constant there is no change in temperature during a change in state.
4. If there is an increase in pressure there will be an increase in temperature and the temperature will vary directly with the pressure.
5. The flow of heat is always from a warm body to a colder body.
6. Energy is convertible, which means heat energy may be converted to mechanical energy or mechanical energy may be converted to heat energy.

The compression system is a closed system. The cycle repeats itself over and over, changing from a liquid to a gas and back to a liquid. The system is constructed so that a controlled amount of fluid (known as the refrigerant) flows through a cycle at a certain predetermined pressure. The refrigerant will absorb heat in a low-pressure zone (known as the evaporator). The heat is then given up in a high-pressure zone (known as the condenser).

Four basic steps are involved in the Refrigeration Cycle:

1. evaporation
2. compression
3. condensation
4. pressure reduction

In assignment X-B-2 we will cover these in detail as they apply to the compression cycle.

Reference: *Principles of Refrigeration*, Dossat

Procedure: Study the information and reference, then do the following assignment and be prepared to discuss it in class.

Assignment:

1. Why is a refrigeration cycle a closed system?
2. Describe the six basic Laws of Refrigeration.
3. List the four basic steps in a refrigeration cycle.
4. At what point in the cycle does the refrigerant absorb heat?
5. At what point in the cycle does the refrigerant give up heat?

Objectives: Upon completion of this lesson, the student will:

1. Be able to describe a compression cycle.
2. Be able to tell where the system divides into a high- and low-pressure side.
3. Know the behavior of gases and liquids in the compression cycle.

Information: The basic cycle is made up of a high-pressure side and a low-pressure side. It consists of changing a liquid to a gas and the gas back to a liquid. The liquid or gas is called a refrigerant and is the medium from which the cooling effect on a substance is obtained.

Using the schematic X-B-2-1 trace the cycle:

The liquid refrigerant leaves the receiver (1) under pressure and passes through an expansion valve or a throttling device (2) that regulates its flow. At this point there is a drop in pressure. The low-pressure liquid passes to the evaporator (3) where it turns to a low-pressure vapor. In the process of changing from a liquid to a vapor it picks up heat from the area causing the area to become cool. The low-pressure vapor enters the suction side of the compressor (4) where it is compressed to a high pressure gas. From here it flows to the condenser, where it is cooled and becomes a high-pressure liquid. This liquid goes to the receiver and the cycle begins again.

The four steps involved in the compression cycle require certain equipment:

1. **Evaporator** – high-pressure liquid refrigerant passes through a metering device where it drops in pressure. It enters the evaporator as a low-pressure liquid. The pressure remains constant to induce evaporation. By using the latent heat of evaporation of the refrigerant, which it absorbs during this change in state, a cooling effect is produced.
2. **Compressor** – the refrigerant enters the evaporator as a low-pressure liquid. It changes its state as it passes through the evaporator and leaves the evaporator as a low-pressure vapor. As it enters the suction line to the compressor, it increases in temperature and becomes a slightly superheated vapor. (A vapor at a higher temperature than its corresponding pressure). The compressor causes the low pressure vapor to be compressed and discharges it to the condenser at a higher pressure and temperature.
3. **Condenser** – the high pressure and high temperature vapor enters the condenser in a superheated state. In the condenser heat is removed and the refrigerant changes from its vapor state to a liquid state.

4. **Receiver** – the liquid refrigerant still under high pressure enters the receiver. The receiver acts as a storage place in the cycle. The liquid refrigerant leaves the receiver under high pressure on its way to the evaporator. The throttling device at the evaporator controls the flow of refrigerant, it separates the high pressure and the low pressure points in the system, and helps control the evaporator pressure. *THE CYCLE NOW REPEATS ITSELF.*

The behavior of gases and liquids in the cycle may best be explained using the schematic X-B-2-2.

To better understand the behavior of gases and liquids in a refrigeration system, trace the action in the following sketch taking particular notice of the temperatures and pressures and where changes of state take place in the system.

Starting at the liquid receiver (1) high-temperature, high-pressure refrigerant in a liquid state passes through the liquid lines (2) to a metering device (3). This may be an expansion valve, or a float-controlled valve. They will be discussed in later units. At this point there is a change in state and a drop in both temperature and pressure. The refrigerant now in a liquid vapor mixture enters the evaporator (5). The refrigerant, as it passes through the evaporator, absorbs heat and vaporizes at a constant temperature and pressure as indicated at points (6) and (7). The saturated vapor (7) is drawn to the suction side of the compressor (9).

As it passes through the suction line (8), it picks up heat from the air surrounding the suction line and becomes a superheated vapor (superheated vapor is vapor at a higher temperature than its corresponding pressure). In the compression process both the temperature and pressure of the superheated vapor (10) increases. The superheated vapor passes through the discharge line to the condenser (11) at which point heat is removed and the superheated vapor starts turning into a liquid vapor mixture (13). Then it turns into a saturated liquid state (14) and finally enters the liquid receiver (1). It is now ready to begin the cycle again.

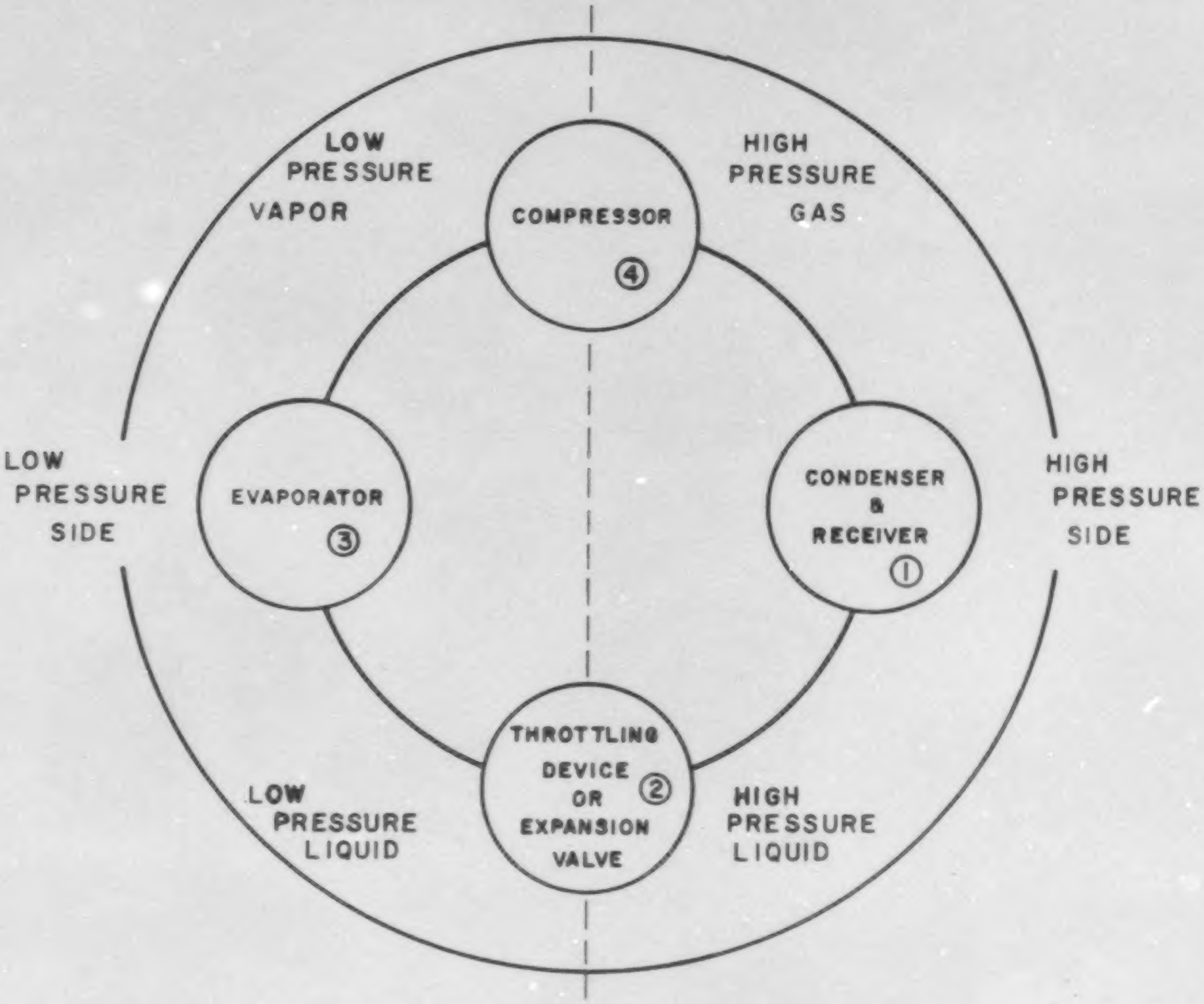
Reference: *Principles of Refrigeration,* Dossat

Procedure: Study the schematics and listed reference; then do the following assignment and be prepared to discuss it in class.

Assignment:

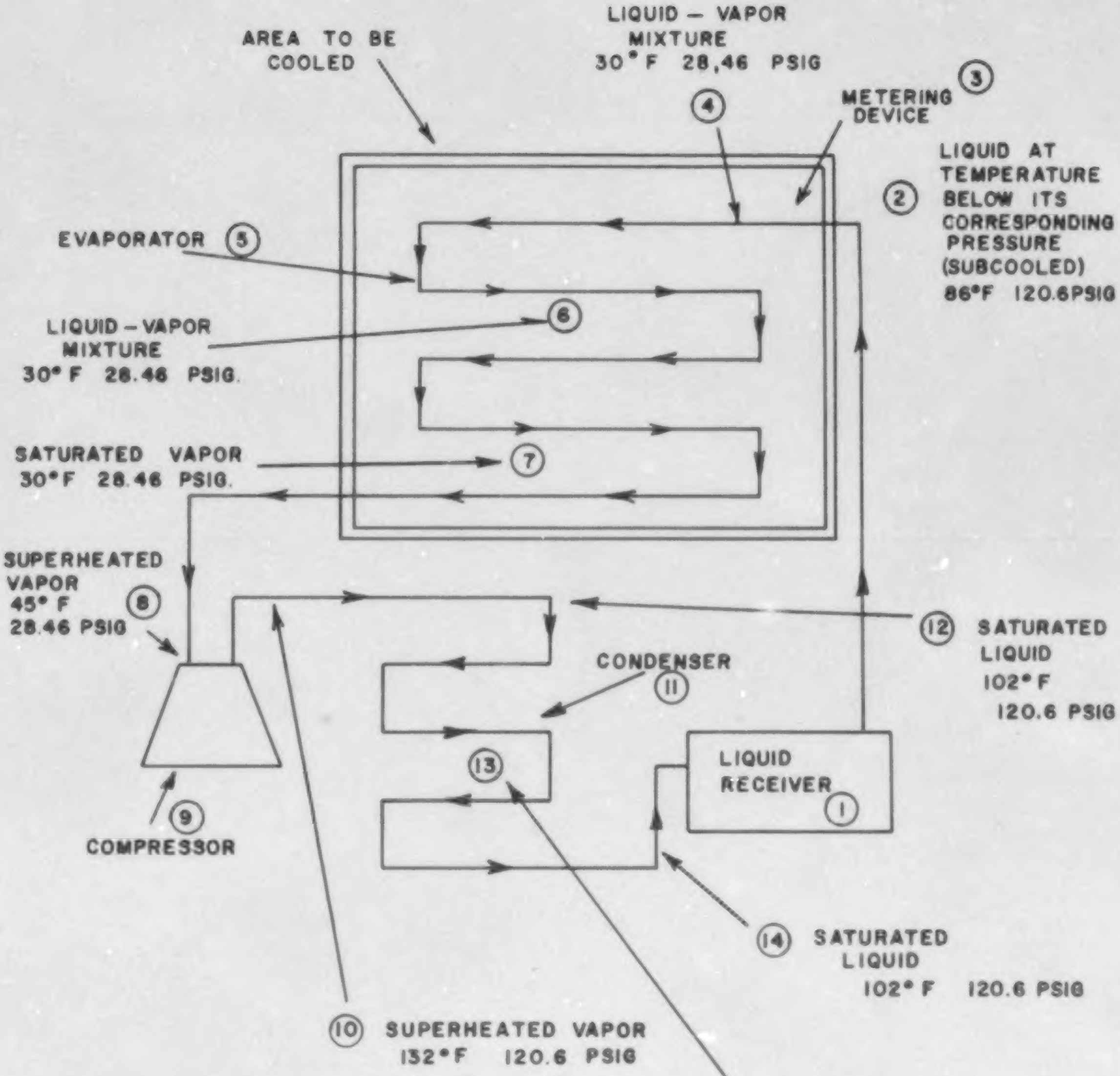
1. Explain where in the system the high-pressure liquid turns into a low-pressure liquid.
2. What causes the low-pressure liquid to turn into a low-pressure vapor? Where does this take place?

3. At what point in the system does the liquid refrigerant first start to change its state?
4. What is meant by:
    a. superheated vapor
    b. saturated vapor
5. Describe the functions performed by:
    a. evaporators
    b. compressors
    c. condensers
    d. receivers
    e. metering devices


LOW
PRESSURE
VAPOR
COMPRESSOR
④
HIGH
PRESSURE
GAS
LOW
PRESSURE
SIDE
EVAPORATOR
③
CONDENSER
&
RECEIVER
①
HIGH
PRESSURE
SIDE
THROTTLING
DEVICE
OR
EXPANSION
VALVE
②
LOW
PRESSURE
LIQUID
HIGH
PRESSURE
LIQUID

Compression Cycle

Fig. X-B-2-1


AREA TO BE COOLED
LIQUID — VAPOR MIXTURE 30° F 28,46 PSIG ④
METERING DEVICE ③
② LIQUID AT TEMPERATURE BELOW ITS CORRESPONDING PRESSURE (SUBCOOLED) 86°F 120.6PSIG
EVAPORATOR ⑤
LIQUID - VAPOR MIXTURE 30° F 28.46 PSIG. ⑥
SATURATED VAPOR 30°F 28.46 PSIG. ⑦
SUPERHEATED VAPOR 45° F 28.46 PSIG ⑧
⑫ SATURATED LIQUID 102° F 120.6 PSIG
CONDENSER ⑪
⑬
LIQUID RECEIVER ①
⑨ COMPRESSOR
⑭ SATURATED LIQUID 102° F 120.6 PSIG
⑩ SUPERHEATED VAPOR 132°F 120.6 PSIG
LIQUID VAPOR MIXTURE 102°F 120.6 PSIG

TEMPERATURE AND PRESSURE
COMPRESSION CYCLE SHOWING

Fig. X-B-2-2

Objective: Upon completion of this lesson, the student will understand the basic principles of the absorption refrigeration system.

Information: The absorption system is a non-mechanical refrigeration system that uses a substance with the ability to absorb a vapor when it is cool and release it when heated. Two substances are used; one is known as the refrigerant and the second is the absorbent. Several possible combinations of these substances are:

Absorbent	Refrigerant
a. Water	Ammonia
b. Lithium Chloride	Water
c. Lithium Bromide	Water

An absorption system consists of the following basic parts shown in Figure X-C-1-1:

a. Evaporator
b. Absorber
c. Generator
d. Condenser

The evaporator and the condenser serve the same purpose as in the compression system. The absorber and the generator are comparable to the compressor in the compression system. The absorber acts as the suction side of the compressor by absorbing the refrigerant; and the generator acts as the discharge side by forcing the refrigerant gas into the condenser.

The most commonly used refrigerant in an absorption refrigeration system is ammonia. Vapors from ammonia may be absorbed in large quantities by cool water at temperatures between 90° and 100° F.

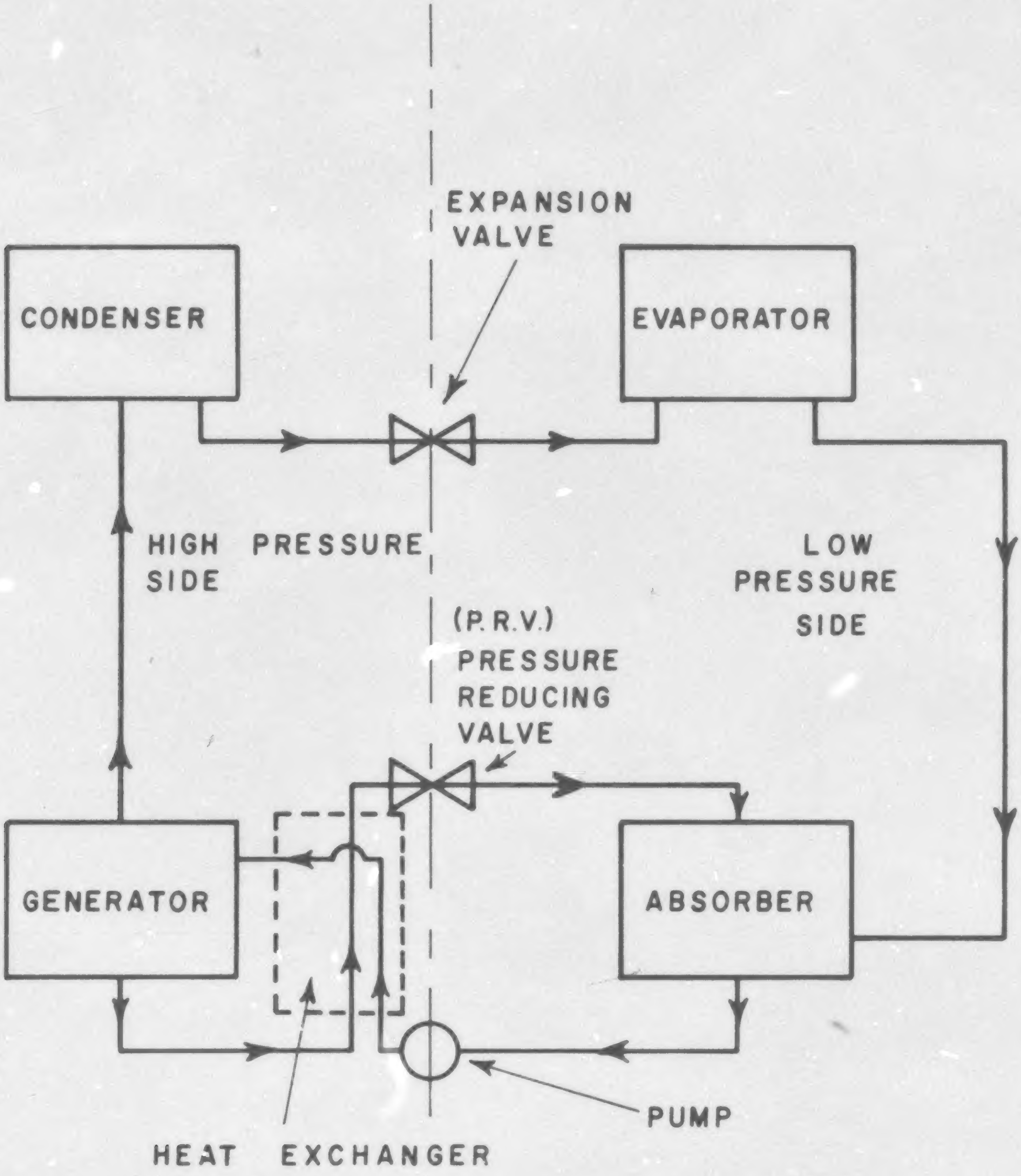
Absorption systems may be continuous or intermittent in operation and used in domestic or commercial systems.

Reference:
1. *Principles of Refrigeration*, Dossat
2. *Refrigeration, Air Conditioning, and Cold Storage*

Procedure: Study the listed references and information; then the following assignment and be prepared to discuss it in class.

Assignment:
1. What is a non-mechanical refrigeration system?
2. What are the main components in a continuous operating absorption refrigeration system?

3. Name some advantages of the absorption refrigeration system over the mechanical type refrigeration system.
4. What are some refrigerants commonly used in the absorption system?
5. What do you call the material that is used to absorb the refrigerant vapor from the evaporator?


EXPANSION
VALVE
CONDENSER
EVAPORATOR
HIGH PRESSURE
SIDE
LOW
PRESSURE
SIDE
(P.R.V.)
PRESSURE
REDUCING
VALVE
GENERATOR
ABSORBER
PUMP
HEAT EXCHANGER

SCHEMATIC BASIC ABSORPTION REFRIGERATION SYSTEM

Fig. X-C-1-1

Basic Absorption Refrigeration Cycle — Assignment X-C-2

Objectives: Upon completion of this lesson, the student will:

1. Know the basic absorption refrigeration cycle.
2. Know the purpose of the components in the cycle.
3. Know how the cycle operates.

Information: The basic absorption cycle consists of four major components:

a. Generator
b. Absorber
c. Evaporator
d. Condenser

A metering device (throttling valve) and pump are also required for the conventional system.

In the ammonia-water system, ammonia is the refrigerant and a solution of ammonia and water is the absorbent. A strong aqua solution contains as much ammonia as possible, so it has a low affinity for ammonia. A weak aqua solution contains considerably less ammonia than a strong aqua solution and has a high affinity for ammonia.

When heat is added to the strong solution in the generator, the ammonia vaporizes and is driven out of solution into the condenser where it is liquified. The liquid refrigerant passes through a metering valve to the evaporator where heat is transferred to the refrigerant from the surrounding medium. The weak aqua solution passes from the generator through a throttling valve into the absorber where it is sprayed or otherwise exposed to the ammonia vapor from the evaporator. Absorption of the ammonia vapor forms a strong solution and lowers the pressure in the absorber; this induces more vapor from the evaporator. The strong solution is pumped back to the generator to begin a new cycle.

A heat exchanger is added to the system to make the cycle more efficient. The heat exchanger serves two purposes. It adds heat to the strong solution and cools the weak solution. Cooling the weak solution saves on the amount of cooling required to be done in the absorber.

Now we can review the cycle. The refrigerant absorbs heat from some medium in the evaporator. From there the refrigerant is absorbed by the absorbent to form a strong solution. This strong solution is pumped to a generator where it is heated,causing the refrigerant vapor to be removed to the condenser. The strong absorbent solution again becomes a weak solution and is used over again. The refrigerant vapor is condensed and returns to the evaporator through an expansion valve. This cycle is continous.

Reference:

1. *Principles of Refrigeration,* Dossat
2. Manufacturers' data sheets and catalogs

Procedure: After having studied the information and listed references, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What does the term *weak solution* mean?
2. What does the term *strong solution* mean?
3. The refrigerant in the condenser changes to what state? Explain why?
4. Explain the purpose of the main components of an absorption refrigeration system.

Objectives: Upon completion of this lesson, the student will:

1. Understand the basic principles of the Steam Jet system.
2. Understand the Steam Jet refrigeration system cycle.
3. Know the purpose of the components in the Steam Jet system.

Information: The Steam Jet Refrigeration system is used for air conditioning and for various processes in industry where steam and condensing water are available. Refrigeration requirements are limited to temperatures above 32° F. The system can operate with low-pressure steam and can use exhaust steam from different equipment operating at higher pressures.

The object of this system is to lower the pressure in the evaporator, which lowers the boiling point of the water. This causes evaporation at a rapid rate which cools the water returning to the evaporator. The Steam Jet ejector draws the vapor out of the evaporator, compresses it in a nozzle, and sends it to the condenser at a high velocity. The condenser condenses the vapor with cooling water and the condensate pump removes it from the condenser. The chilled water in the evaporator is pumped to the air conditioning or refrigeration space.

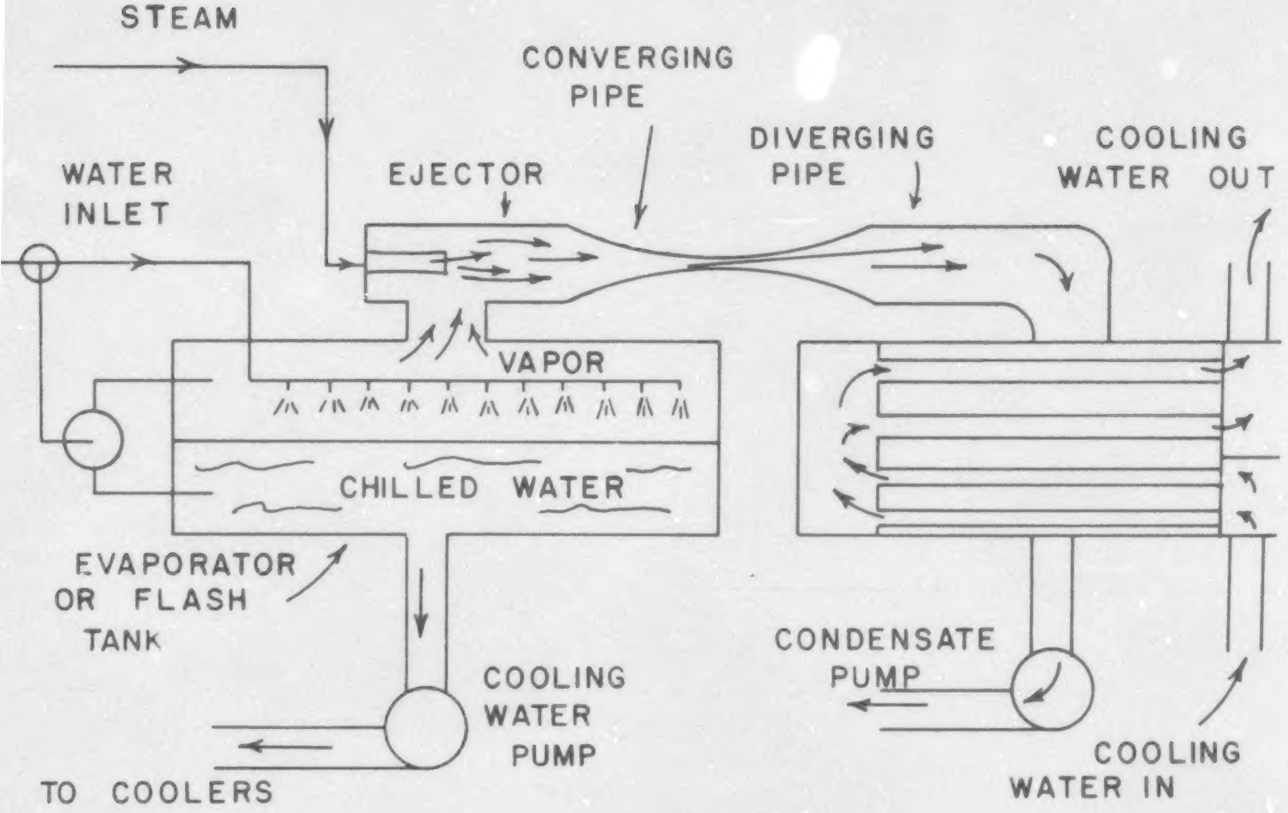
The system consists of the following components in Sketch X-D-1-1:

1. Steam ejector assembly
2. Evaporator (flash tank or chiller)
3. Condenser
4. Circulating pump
5. Condensate pump

The purpose of these components are as follows:

1. Steam ejector assembly – steam expands through the nozzle dropping in pressure and increasing in velocity. This causes vapor from the evaporator to be drawn from that area into the swift moving steam. This mixture then enters the converging pipe to the condenser.
2. Evaporator – sometimes referred to as a flash tank. It is used to collect the chilled water from the air conditioning or refrigeration system. The low pressure in this tank causes the return water to flash into a vapor, thus reducing its temperature.
3. Condenser – vapor and steam are condensed using a surface condenser. Note: The steam and cooling water do not mix in a surface condenser.
4. Condensate pump – returns the condensate to the boiler feedwater system.

The Steam Jet refrigeration system is classified as a non-mechanical type system. It has very few moving parts and can be located anywhere.


STEAM
CONVERGING PIPE
DIVERGING PIPE
COOLING WATER OUT
WATER INLET
EJECTOR
VAPOR
CHILLED WATER
EVAPORATOR OR FLASH TANK
CONDENSATE PUMP
COOLING WATER PUMP
TO COOLERS
COOLING WATER IN

STEAM — JET REFRIGERATION

SYSTEM

Fig. X-D-1-1

References:

1. *Principles of Refrigeration*, Dossat
2. *Refrigeration, Air Conditioning, and Cold Storage*
3. Manufacturers' data sheets and catalogs

Procedure: After having read the information and studied the reference, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What pressure exists in the evaporator or flash tank?
   Explain how this is accomplished.
2. How does the condenser work?
3. In what respect is the Steam Jet system comparable to the absorption system?
4. Where would a Steam Jet Refrigeration system be used and for what purpose?
5. What refrigerant is used in this type of system?
6. Describe the principles of refrigeration as it applies to a Steam Jet system?

Objectives: Upon completion of this lesson, the student will:

1. Know the difference between the Direct and Indirect Refrigeration systems.
2. Be familiar with the application of each system.
3. Be familiar with the secondary refrigerants.

Information: Any heat transfer surface onto which a refrigerant is expanded and evaporated in order to produce a cooling effect is called a *direct-expansion* evaporator, and the liquid is called a *direct-expansion refrigerant.* A Direct Expansion System is one in which the evaporator is in direct contact with the space or material being refrigerated, or it is located in air ducts communicating with such spaces.

Sometimes it is either inconvenient or uneconomical to circulate a direct-expansion refrigerant to the area where the cooling is required. In such cases an *Indirect Refrigerating* System is employed. Water, brine or some other suitable liquid is chilled and then pumped through appropriate piping to the space or product being refrigerated. The chilled liquid, called a *secondary refrigerant*, may be circulated directly around the refrigerated product or vessel, or it may be passed through an air-cooling coil. In either case the secondary refrigerant warmed by the absorption of heat from the refrigerated space or product is returned to the chiller to be chilled and recirculated. Indirect refrigerating systems are usually employed to advantage in any installation where the space or product to be cooled is located a considerable distance from the condensing equipment. The reason is that long direct-expansion refrigerant lines are not practical. They are expensive to install, require a large refrigerant charge, create oil return problems, and cause refrigerant pressure losses which reduce the capacity and efficiency of the system. Leaks are more serious and are more likely to occur in refrigerant piping than in water or brine piping.

Indirect refrigeration is required in many industrial process-cooling applications where it is often impractical to maintain a vapor tight seal around the product or vessel being cooled. Indirect systems are used to an advantage in any application where the leakage of the refrigerant may cause contamination or other damage to a stored product.

Secondary refrigerants commonly used are water, calcium chloride (solution), sodium chloride solution (both of these solutions are known as brine), ethylene and propylene glycols, methanol, and glycerin. Water is usually used as the secondary refrigerant in large air conditioning systems and in industrial process-cooling installations where the temperatures maintained are above the freezing point of water. Water cannot be employed as a secondary refrigerant in any application where the temperature to be maintained is below the freezing point of water. A brine solution is often used in such cases. Brine is the name given solutions resulting from various salts being dissolved in water. If a salt is dissolved in water, the freezing point of the resulting brine will be below the freezing point of pure water. Two types of brine are commonly used in refrigeration practice:

1. Calcium chloride
2. Sodium chloride

Certain water-soluble compounds generally described as antifreeze agents are often used to depress the freezing point of water. The most widely known antifreeze agents are:

1. Ethylene glycol
2. Propylene glycol
3. Methanol
4. Glycerine

All these compounds are soluble in water in all proportions.

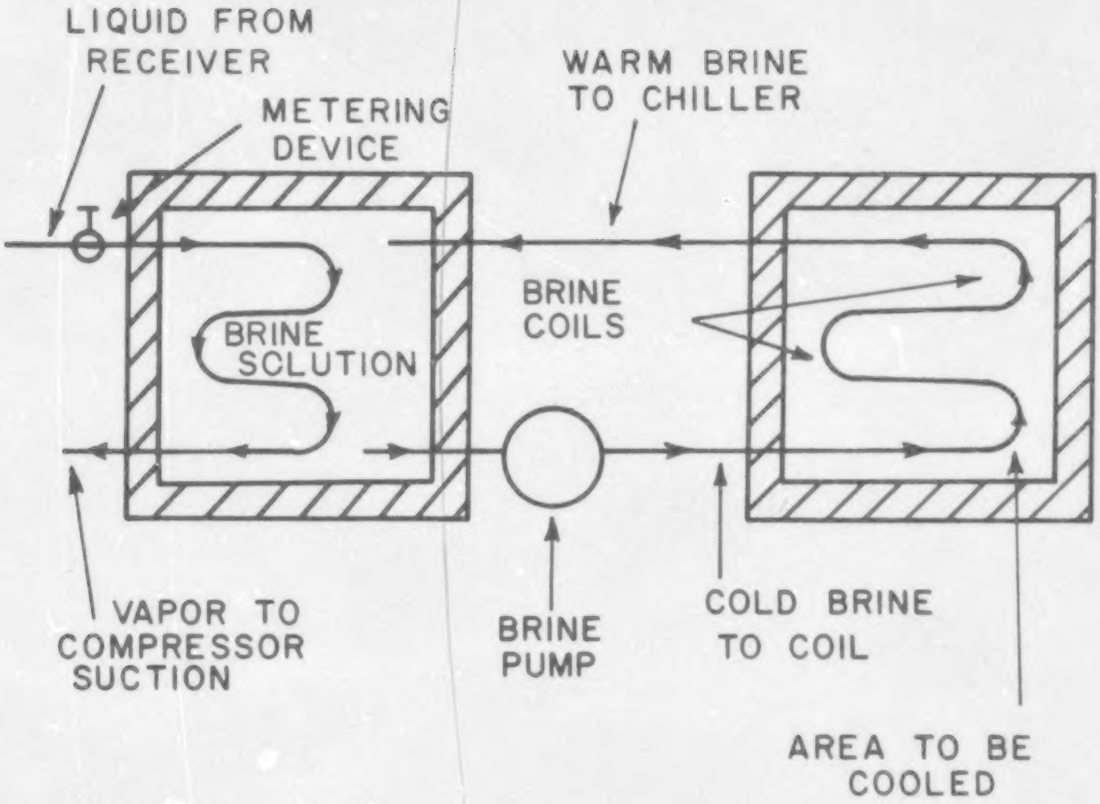
References:

1. *Principles of Refrigeration*, Dossat
2. Manufacturers' data sheets and catalogs

Procedure: After having read the information and studied the listed references, do the following assignment and be prepared to discuss it in class.

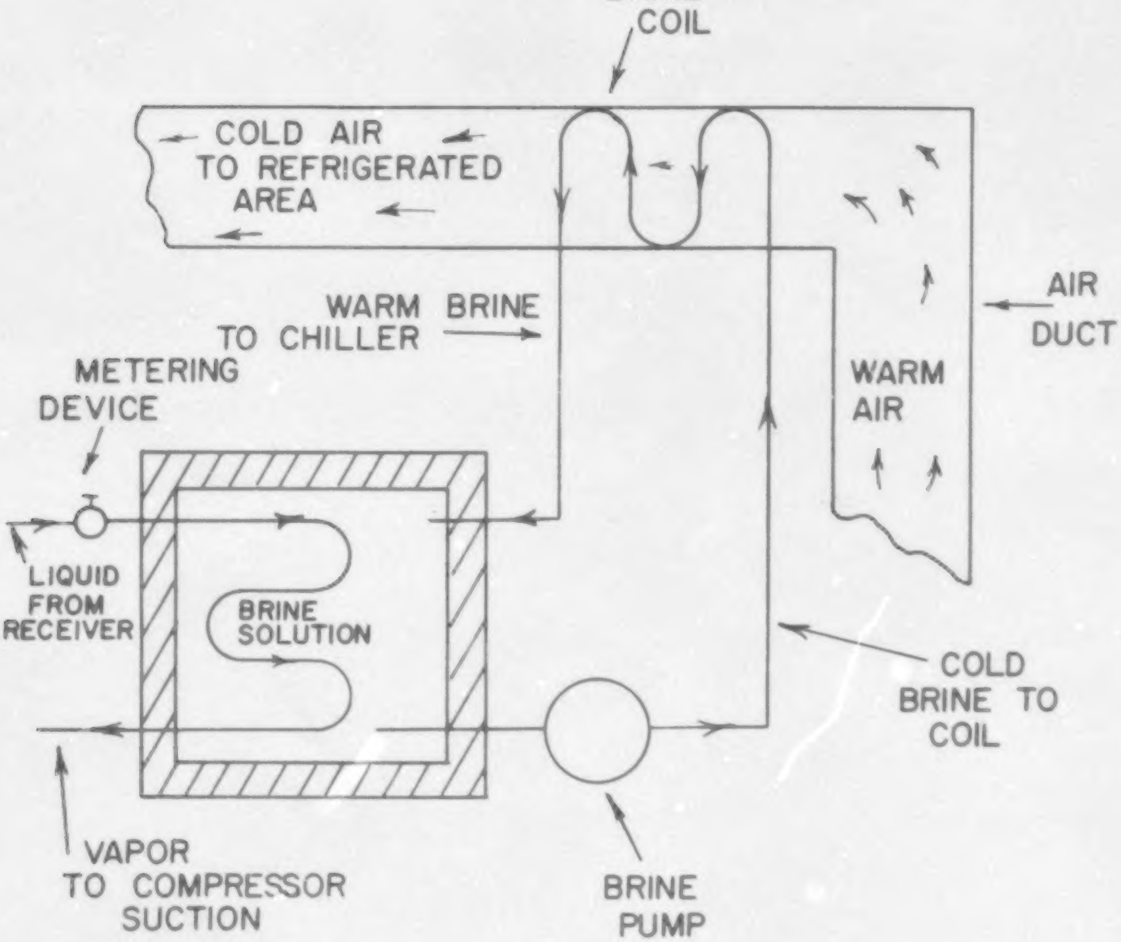
Assignment

1. Briefly describe a Direct Expansion System of Refrigeration.
2. Briefly describe an Indirect Expansion System of Refrigeration.
3. Why are indirect systems used? What are their applications?
4. Describe what is meant by a secondary refrigerant.
5. Can water be used as a secondary refrigerant for all applications? Explain your answer.
6. What is brine?
7. Where is it used?
8. What are the advantages of using brine?
9. What are some of the soluble compounds used with water? Explain why they are used.


LIQUID FROM RECEIVER
METERING DEVICE
WARM BRINE TO CHILLER
BRINE SOLUTION
BRINE COILS
VAPOR TO COMPRESSOR SUCTION
BRINE PUMP
COLD BRINE TO COIL
AREA TO BE COOLED

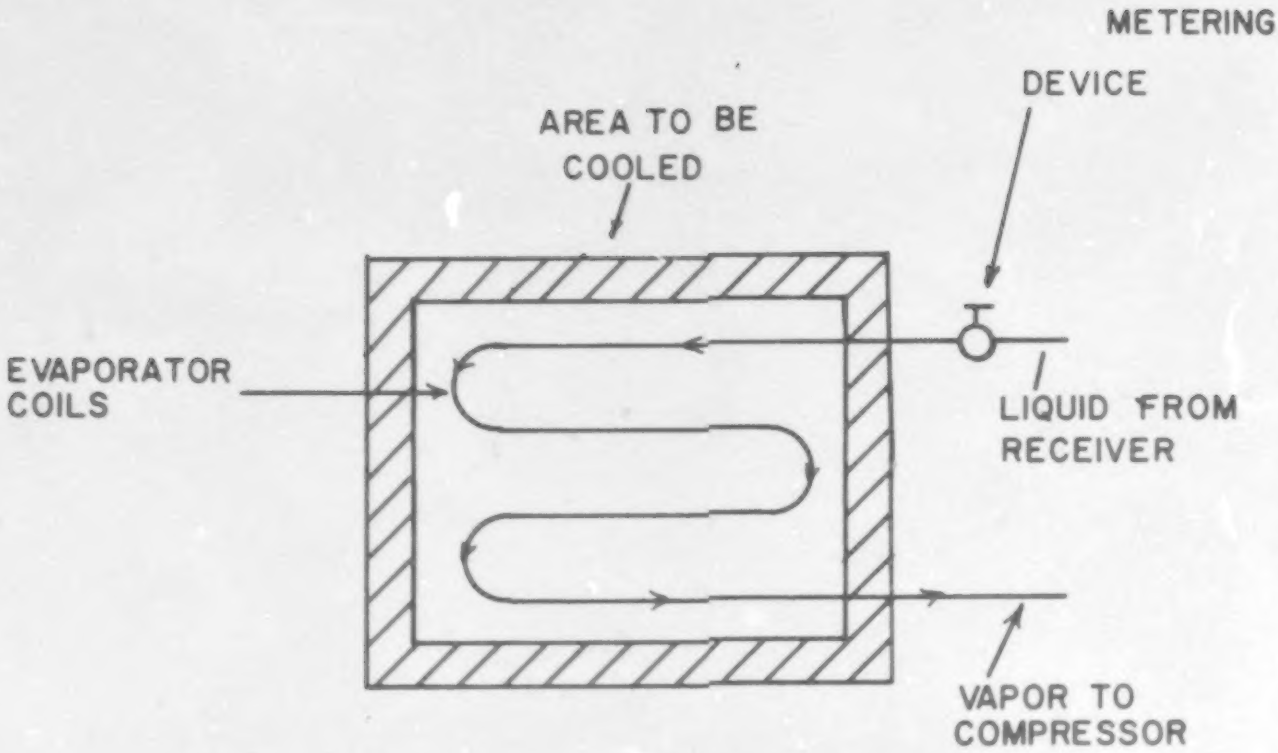
INDIRECT SYSTEM

Fig. X-E-1-1


BRINE COIL
COLD AIR TO REFRIGERATED AREA
AIR DUCT
WARM BRINE TO CHILLER
METERING DEVICE
WARM AIR
LIQUID FROM RECEIVER
BRINE SOLUTION
COLD BRINE TO COIL
VAPOR TO COMPRESSOR SUCTION
BRINE PUMP

INDIRECT SYSTEM-BRINE COIL
IN AIR DUCT

Fig. X-E-1-2


METERING
DEVICE
AREA TO BE
COOLED
EVAPORATOR
COILS
LIQUID FROM
RECEIVER
VAPOR TO
COMPRESSOR

DIRECT-SYSTEM

Fig. X-E-1-3

Objectives: Upon completion of this lesson, the student will:

1. Recognize the types of compressors.
2. Know the purpose of compressors in the Refrigeration Cycle.

Information: Compressors used in refrigeration are sometimes referred to as vapor compressors. There are three principal types:

1. Reciprocating
2. Rotary
3. Centrifugal

The reciprocating compressor is the one most frequently used. Rotary compressors are used in home freezers, refrigerators, and some small commercial installations. Centrifugal compressors will be found on large capacity systems of 50 tons and over.

Since the reciprocating compressor is the one so often used let's look at the parts in Sketches XI-A-1-1 and XI-A-1-2.

The crankshaft (1) transmits the power supplied by a gas engine, a steam engine, or an electric motor to the connecting rod (2). The connecting rod drives the piston (3) which is responsible for creating the suction and the discharge pressures. The suction valve (4) opens on the suction stroke and closes on the discharge or compression stroke. The discharge valve (5) closes on the suction stroke and opens on the compression or discharge stroke.

To explain a complete revolution (piston starting at the highest part of its stroke and returning) we shall again use the same sketches. As the piston moves downward during the suction stroke, it creates a vacuum. This draws the refrigerant as a vapor form into the cylinder. The piston continues downward and the cylinder is filled to capacity. As the piston moves upward the vapor is compressed, causing a higher pressure. The suction valve is closed and the discharge valve opens as the pressure increases.

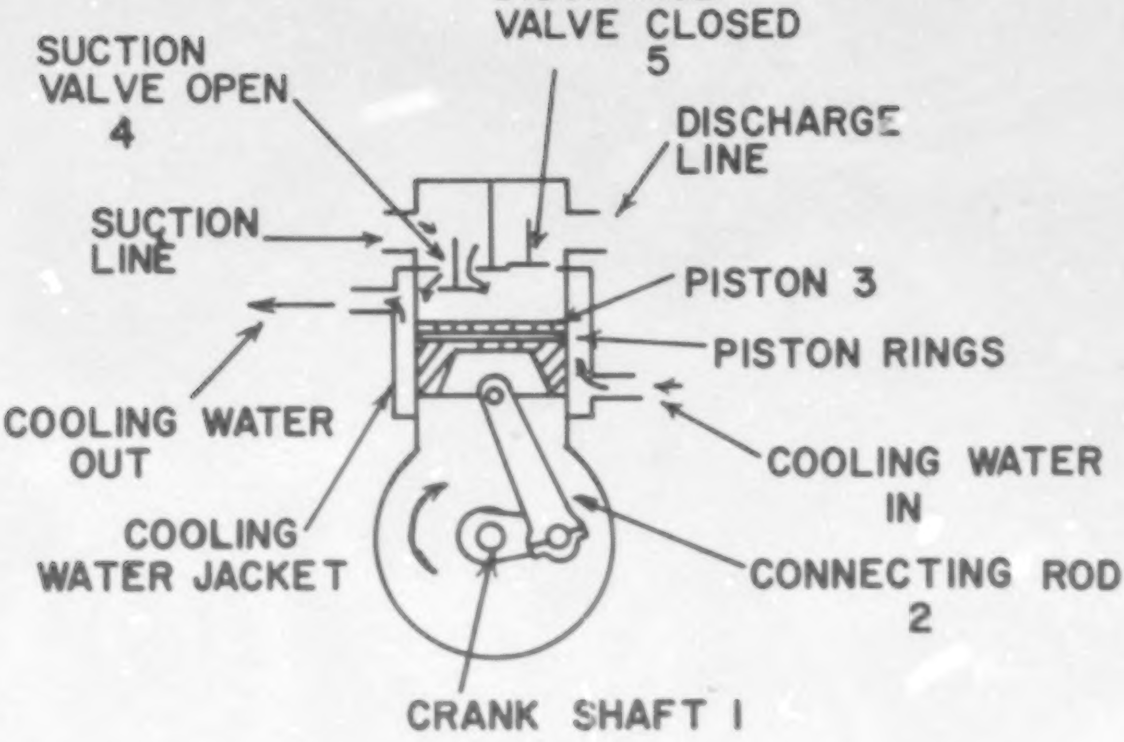
The refrigerant leaves the compressor through the discharge line at a high temperature and pressure. The piston, now on top dead center, is ready to begin another revolution or cycle.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After having read the information and studied the reference, do the following assignment and be prepared to discuss it in class.

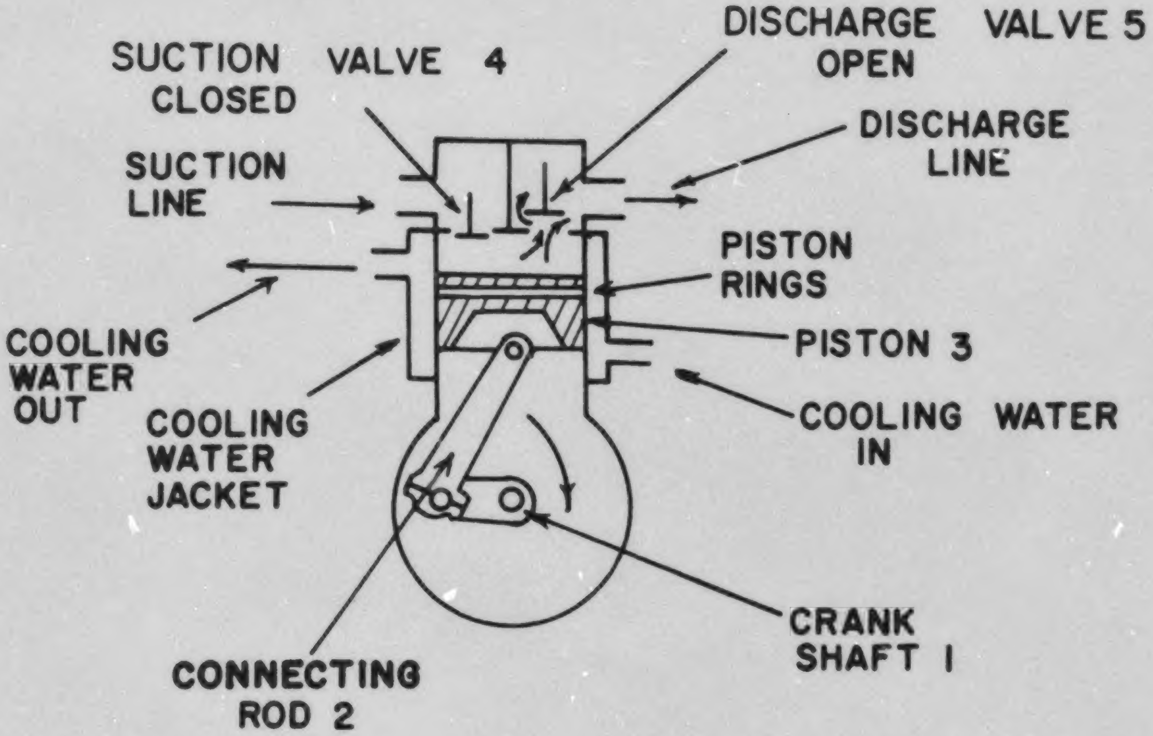
Assignment:

1. List the three types of compressors and state where they are used.
2. Describe one complete revolution or cycle of a reciprocating compressor.
3. In what condition does the refrigerant leave the compressor?
4. What are the functions performed by the compressor?


DISCHARGE VALVE CLOSED 5
SUCTION VALVE OPEN 4
DISCHARGE LINE
SUCTION LINE
PISTON 3
PISTON RINGS
COOLING WATER OUT
COOLING WATER IN
COOLING WATER JACKET
CONNECTING ROD 2
CRANK SHAFT 1

SUCTION STROKE

Fig. X-A-1-1


SUCTION VALVE 4
CLOSED
DISCHARGE VALVE 5
OPEN
DISCHARGE
LINE
SUCTION
LINE
PISTON
RINGS
PISTON 3
COOLING
WATER
OUT
COOLING
WATER
JACKET
COOLING WATER
IN
CRANK
SHAFT 1
CONNECTING
ROD 2

COMPRESSION STROKE

Fig. XI-A-1-2

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of a condenser.
2. Know the different types of condensers.
3. Understand the operation of the different types of condensers.

Information: Upon discharge from the compressor the warm gas enters the condenser where the heat absorbed in the evaporator and the heat of compression is removed, and the gas is converted to a liquid. The condenser is a heat exchanger equipped with heat transfer elements that enable opposing fluids to come in close contact, and the heat passes from the colder to the warmer fluid. There are many types of condensers. The selection must be based on the operating conditions of the system and the type, source and the cost of an available cooling medium.

There are, however, three general types of condensers:

1. Air-cooled
2. Water-cooled
3. Evaporative

The air-cooled condensers use air as the condensing medium. The water-cooled condenser utilizes water to condense the refrigerant. Both air and water are used by the evaporative condenser.

The circulation of air over an air-cooled condenser may be either by natural convection or by action of a fan or blower. The condenser utilizing natural circulation of air is used only on small applications such as domestic refrigerators and freezers. Air-cooled condensers employing fans can be divided into two groups according to the location of the condenser.

1. Chassis-mounted – mounted with the compressor and found in small units.
2. Remote air-cooled units – the condensing units may be mounted indoors or outdoors and are used in sizes up to 100 tons.

Water-cooled condensers are of three basic types:

1. Double-tube (Sketch XI-B-1-1)
2. Shell and tube (Sketch XI-B-1-2)
3. Shell and coil (Sketch XI-B-1-3)

The double-tube condenser consists of two tubes arranged so that one is inside of the other. Water is piped through the inner tube while the refrigerant flows in the opposite direction in the space between the inner and outer tubes. Some air-cooling of the refrigerant is provided in addition to the water cooling.

The shell and tube condenser consists of a cylindrical steel shell in which a number of straight tubes are arranged in parallel and held in place at the ends by the tube sheets. The condensing water is circulated through the tubes while the refrigerant is contained in the shell between the tube sheets. The condensers may be single or multi pass and are available in capacities ranging from one ton to several tons. The shell diameters range from approximately 4" to 60" and the tube lengths vary from three feet to twenty feet.

The shell and coil condenser is made up of one or more bare-tube or finned-tube coils enclosed in a welded steel shell. The condensing water circulates through the coils while the refrigerant is contained in the shell surrounding the coils. Hot refrigerant vapor enters at the top of the shell and condenses as it comes in contact with the water coils, then it drains to the bottom of the shell. As a general rule shell- and coil-type condensers are used for small installations up to approximately 10-ton capacity.

The evaporative condenser is essentially a water conservation device and is in effect a condenser and a cooling tower in a single unit. See Sketch XI-B-1-4. Both air and water are used in the evaporative condenser. The water is pumped from a sump to the spray heads, sprays over the refrigerant coils and returns to the sump. The air is drawn in from the outside at the bottom of the condenser by the action of a blower. It is discharged back to the outside at the top of the condenser.

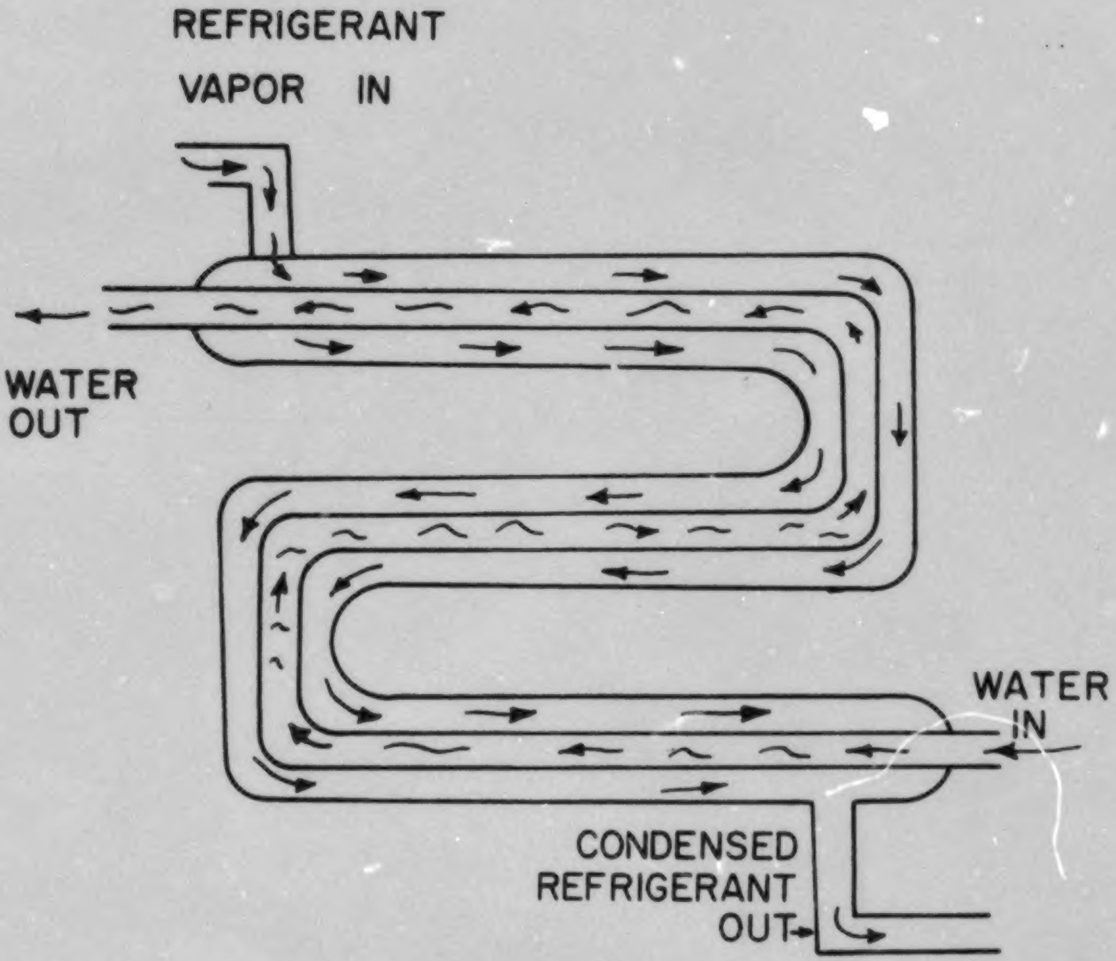
References:

1. *Principles of Refrigeration,* Dossat
2. *Refrigeration, Air Conditioning, and Cold Storage*
3. Manufacturers' data sheets and catalogs

Procedure: After having read the information and references, do the following assignment and be prepared to discuss it in class.

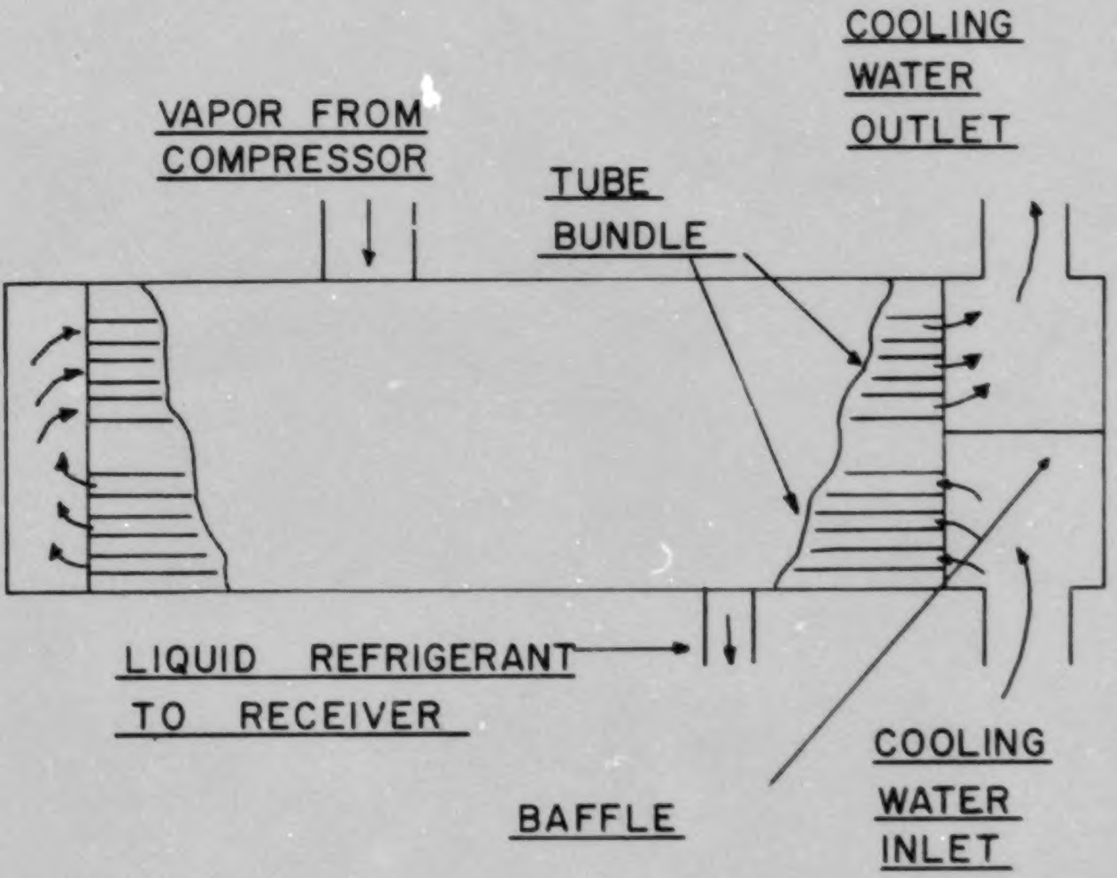
Assignment:

1. Where is the condenser located in the refrigeration system? Explain your answer.
2. What is the purpose of the condenser?
3. What factors determine the type of condenser that is used?
4. Describe an evaporative condenser, its location, and how it operates.
5. Explain the difference between the three general types of condensers.


REFRIGERANT
VAPOR IN
WATER
OUT
WATER
IN
CONDENSED
REFRIGERANT
OUT

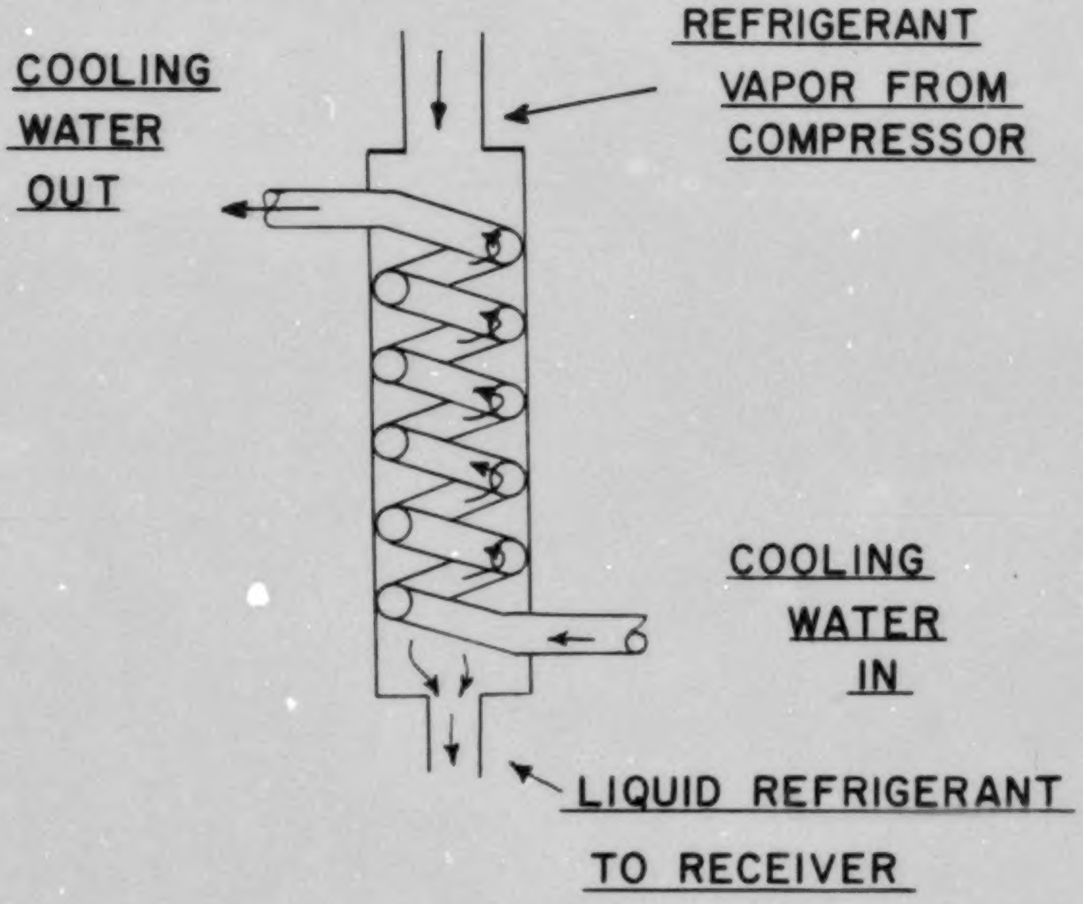
DOUBLE - TUBE WATER COOLED
CONDENSER

Fig. XI-B-1-1


COOLING WATER OUTLET
VAPOR FROM COMPRESSOR
TUBE BUNDLE
LIQUID REFRIGERANT TO RECEIVER
COOLING WATER INLET
BAFFLE

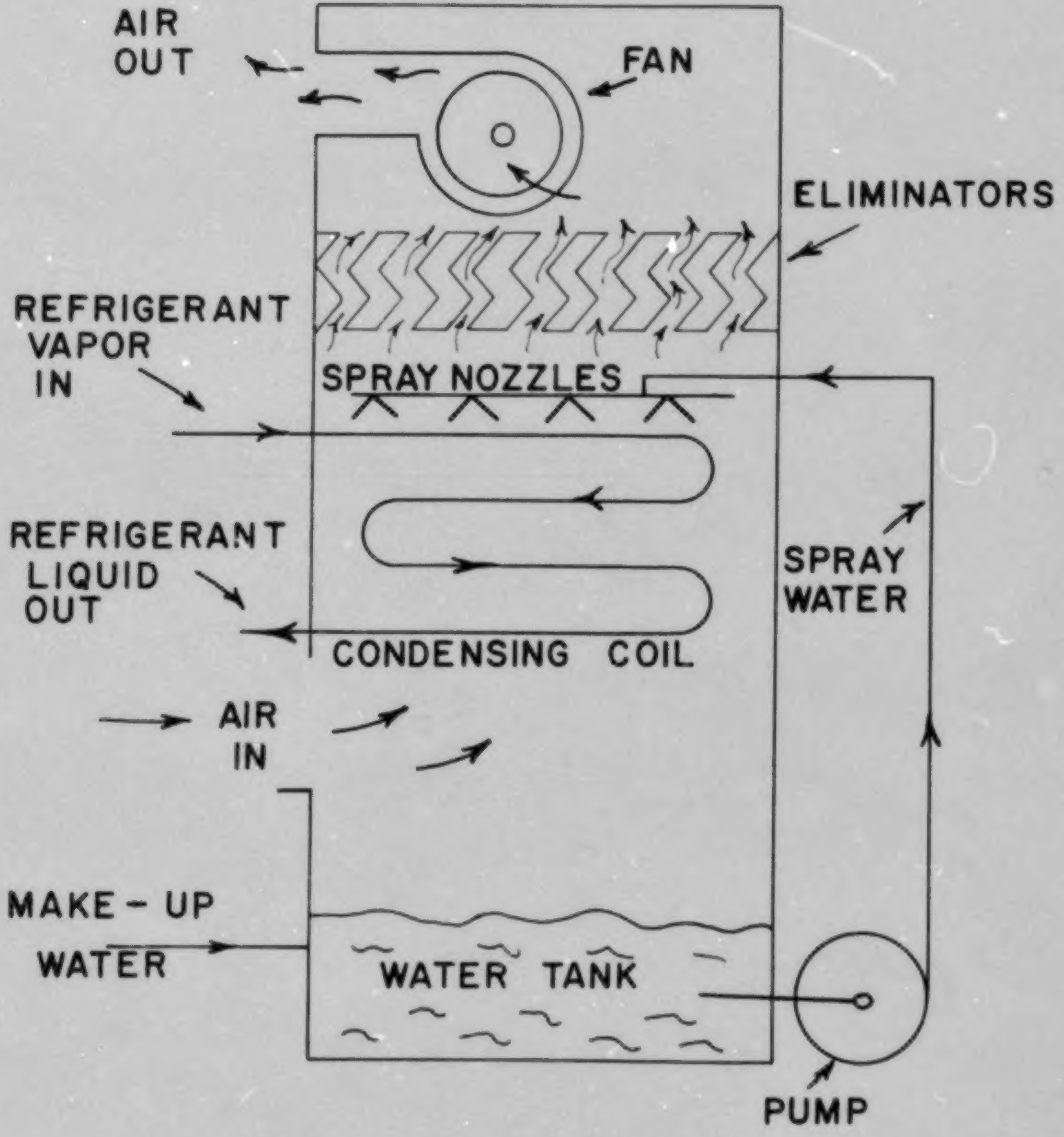
SHELL AND TUBE CONDENSER

Fig. XI-B-1-2


REFRIGERANT VAPOR FROM COMPRESSOR
COOLING WATER OUT
COOLING WATER IN
LIQUID REFRIGERANT TO RECEIVER

SHELL AND COIL CONDENSER

Fig. XI-B-1-3


AIR OUT
FAN
ELIMINATORS
REFRIGERANT VAPOR IN
SPRAY NOZZLES
REFRIGERANT LIQUID OUT
SPRAY WATER
CONDENSING COIL
AIR IN
MAKE - UP WATER
WATER TANK
PUMP

SCHEMATIC - EVAPORATIVE CONDENSER

Fig. XI-B-1-4

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of evaporators.
2. Be able to identify the types of evaporators.

Information: The evaporator may be compared to a boiler. The boiler is a closed vessel containing water under pressure that generates steam by the application of heat. The evaporator in the refrigeration system converts the liquid refrigerant to a vapor by absorbing heat from the surrounding area. The area is cooled in the evaporation process.

Evaporators are classified into two systems – flooded or dry expansion. Figure XI-C-1-1 shows a flooded-type evaporator which is always filled completely with a liquid refrigerant. This level is maintained by some type of float control valve. As the refrigerant boils, the vapor gathers in the accumulator and is drawn off the top by the action of the compressor. The main advantage of a flooded evaporator is that the surface of the evaporator is completely wet with the liquid refrigerant which results in a high rate of heat transfer. The disadvantage is that it requires a large charge of refrigerant and is bulky in size.

Figure XI-C-1-2 shows a dry expansion system. A metering device controls the amount of liquid refrigerant fed into the evaporator. It should be controlled so that all the liquid is vaporized when it reaches the end of the evaporator coils. The amount of refrigerant passing through the metering device depends on the heat load on the evaporator. The amount of liquid found in the dry expansion evaporator varies with the load. The amount of liquid increases the load on the evaporator. This means that the efficiency of a dry expansion evaporator is greatest when the load is greatest because it increases the wetting action and rate of heat transfer with the increase in liquid.

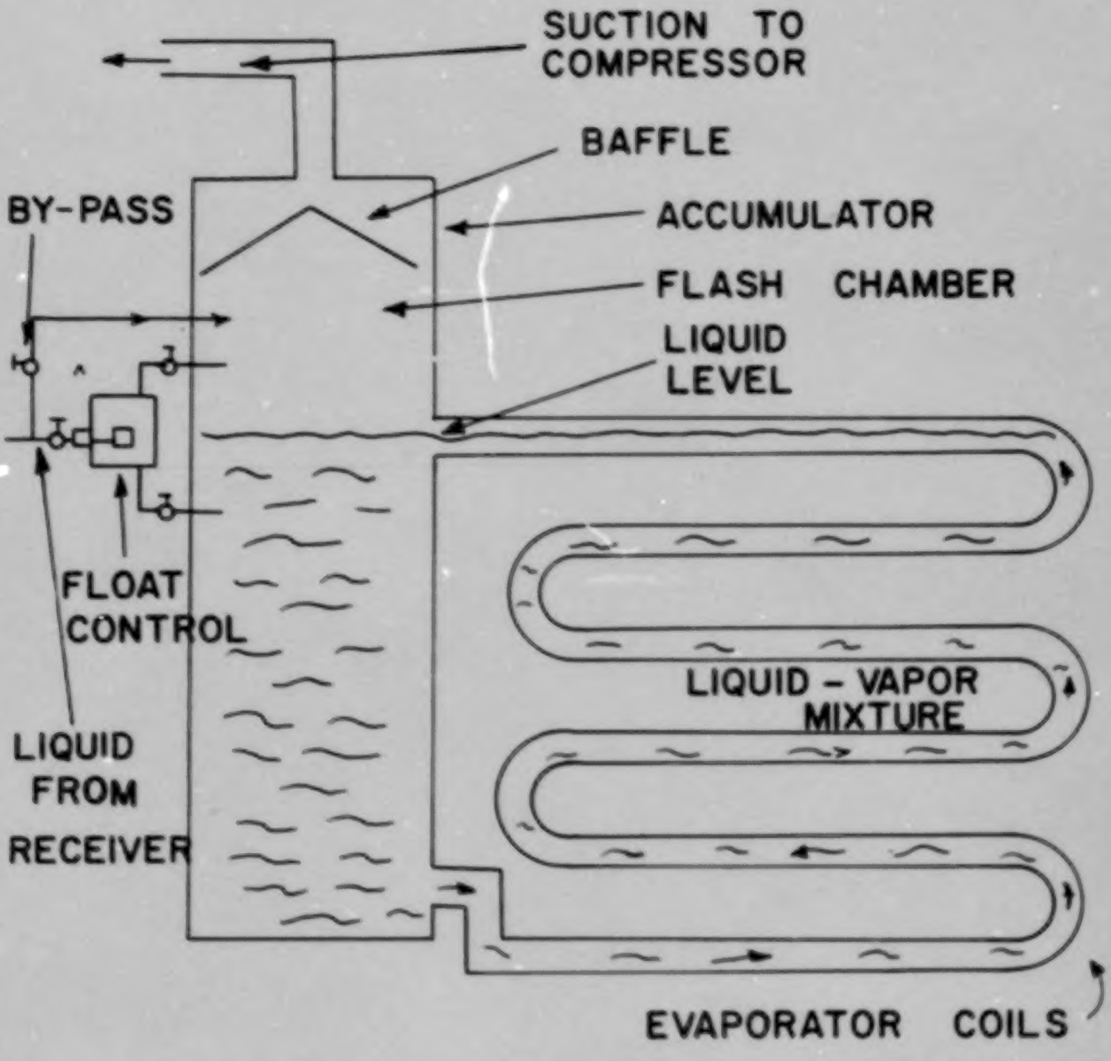
Figures XI-C-1-1, XI-C-1-2, and XI-C-1-3 are examples of the three types of evaporators.

Reference: *Principles of Refrigeration*, Dossat

Procedure: Study the information, the sketches, and the reference; then do the following assignment and be prepared to discuss it in class.

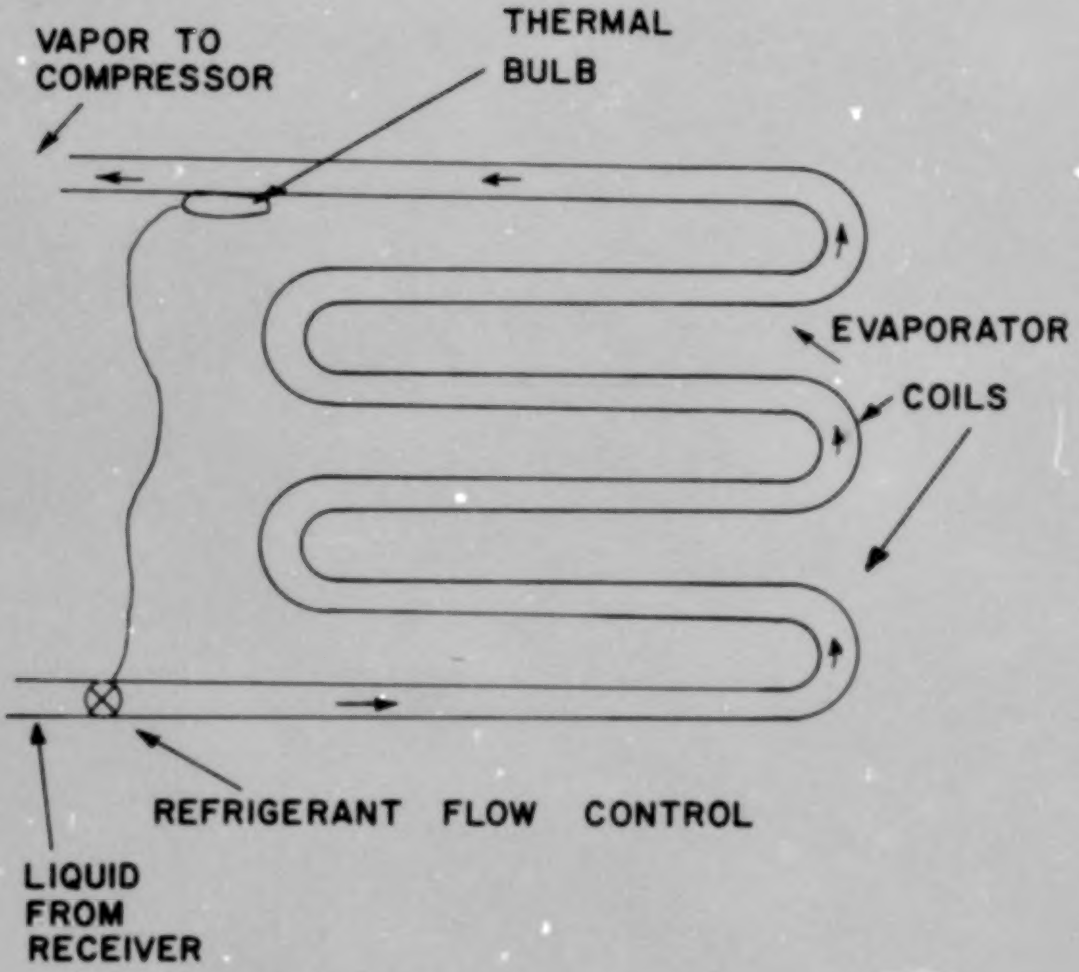
Assignment:

1. What purpose does the evaporator serve in the system?
2. What causes the liquid refrigerant to boil?
3. Briefly describe a flooded and dry expansion system.
4. How does the vapor leave the evaporator?
5. How is the liquid level maintained in a flooded system?


SUCTION TO COMPRESSOR
BAFFLE
BY-PASS
ACCUMULATOR
FLASH CHAMBER
LIQUID LEVEL
FLOAT CONTROL
LIQUID - VAPOR MIXTURE
LIQUID FROM RECEIVER
EVAPORATOR COILS

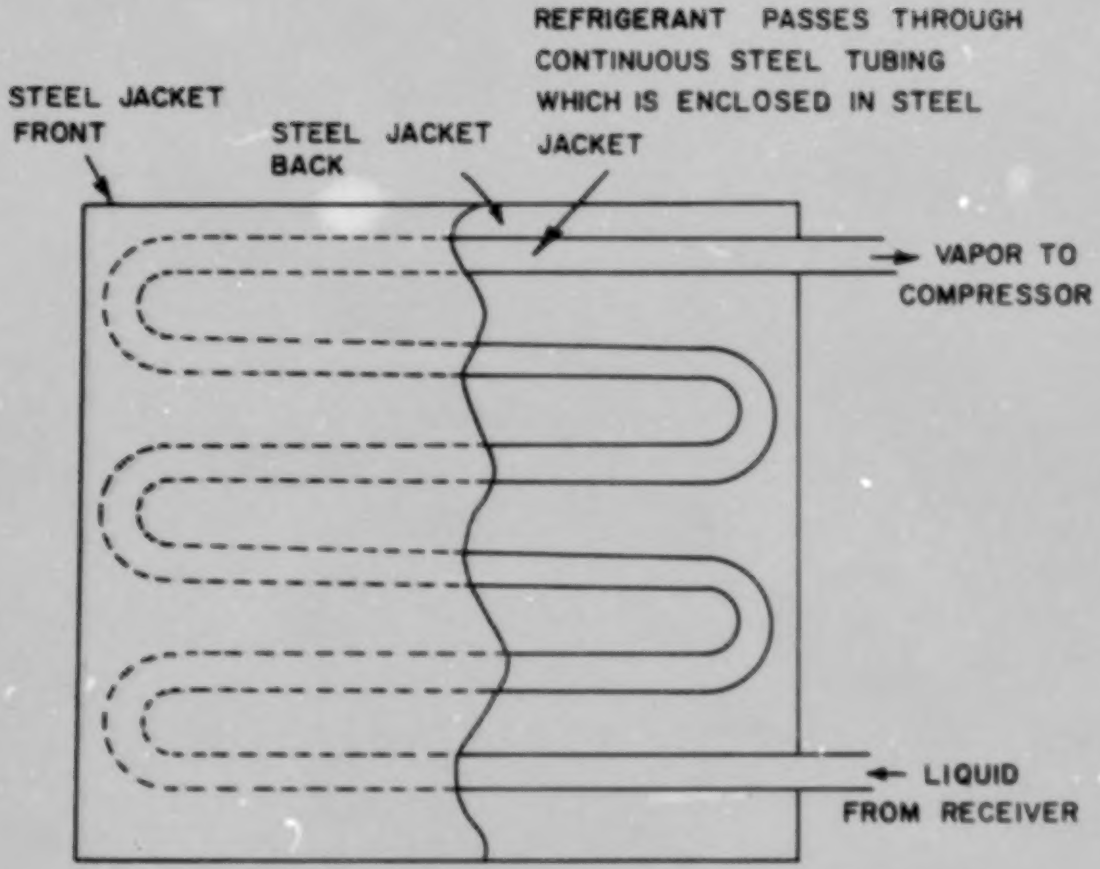
FLOODED - TYPE EVAPORATOR

Fig. XI-C-1-1


VAPOR TO
COMPRESSOR
THERMAL
BULB
EVAPORATOR
COILS
REFRIGERANT FLOW CONTROL
LIQUID
FROM
RECEIVER

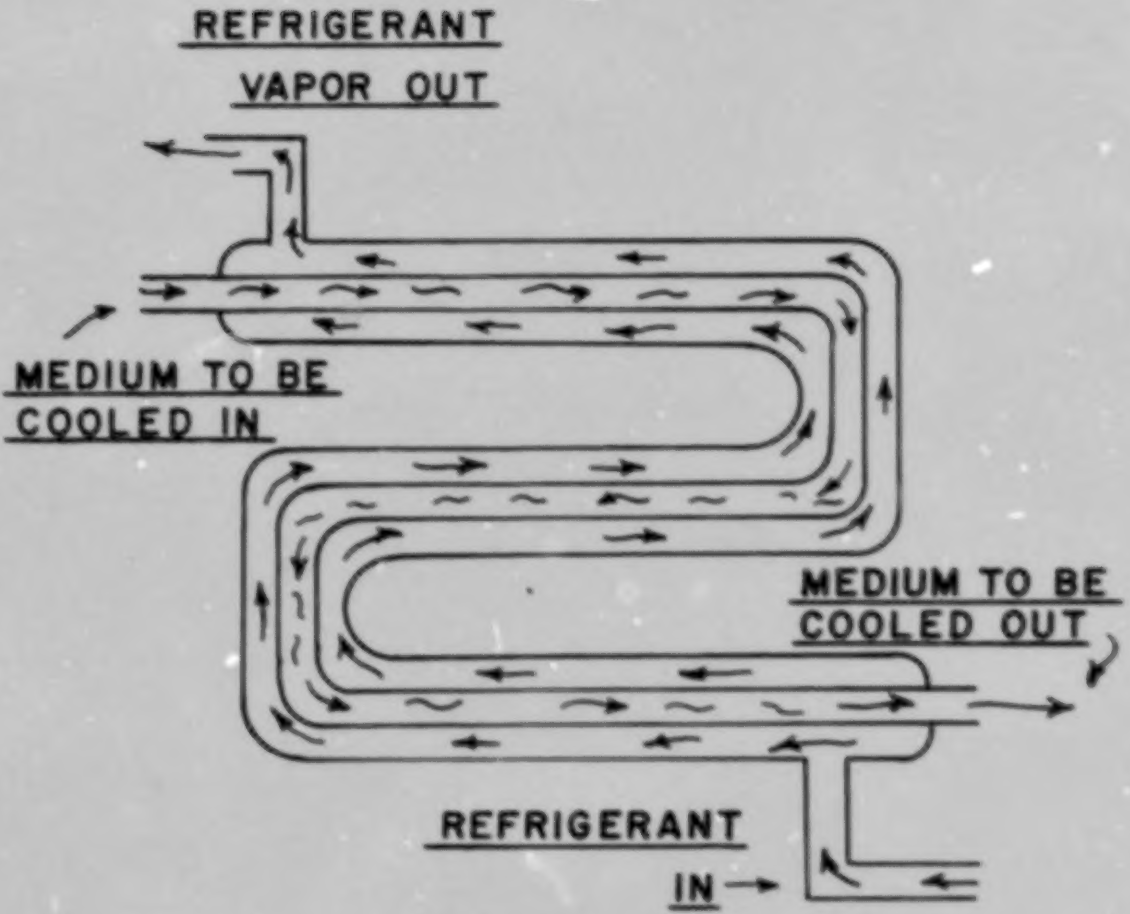
DRY EXPANSION EVAPORATOR

Fig. XI-C-1-2


REFRIGERANT PASSES THROUGH
CONTINUOUS STEEL TUBING
WHICH IS ENCLOSED IN STEEL
JACKET
STEEL JACKET
FRONT
STEEL JACKET
BACK
VAPOR TO
COMPRESSOR
LIQUID
FROM RECEIVER

EVAPORATOR PLATE-TYPE

[illegible] Fig. XI-C-1-3

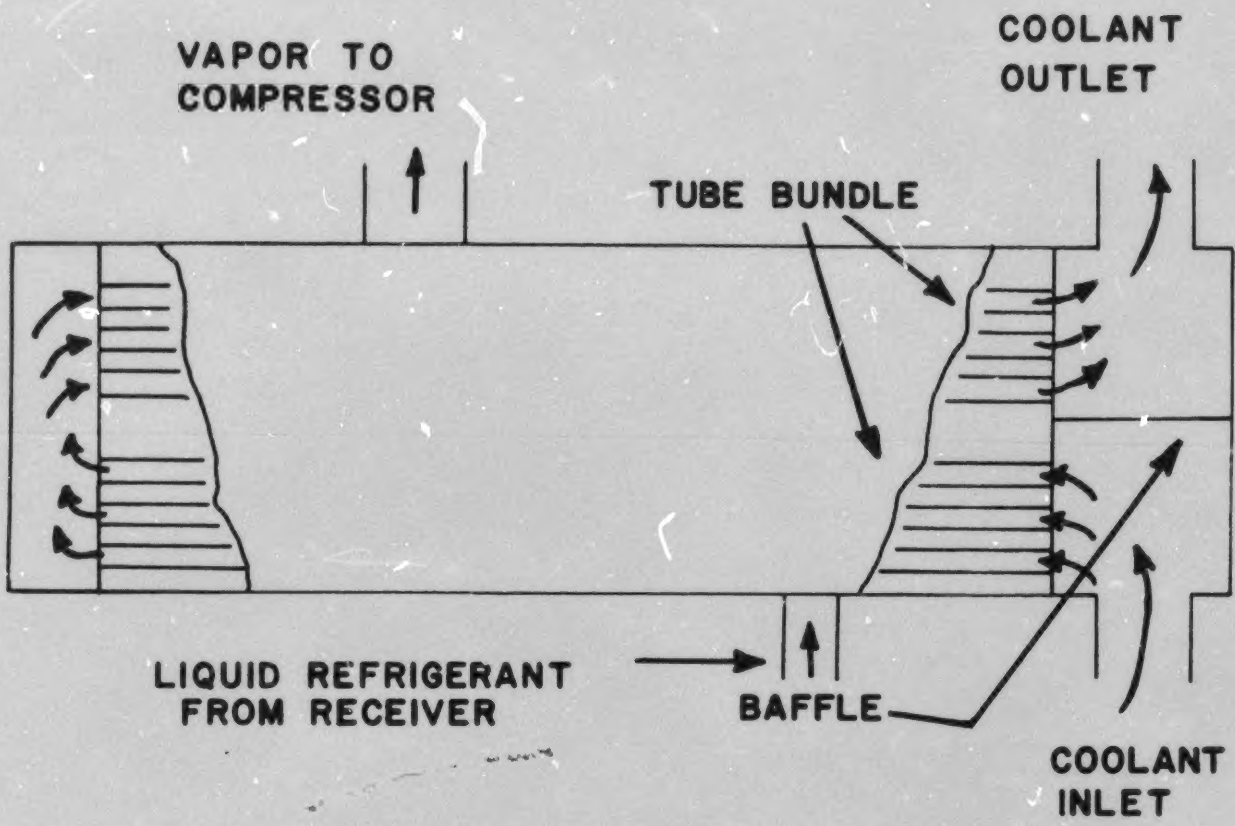

REFRIGERANT
VAPOR OUT
MEDIUM TO BE
COOLED IN
MEDIUM TO BE
COOLED OUT
REFRIGERANT
IN

DOUBLE PIPE TYPE

EVAPORATOR

Fig. XI-C-1-4

II-C-1-4.


VAPOR TO COMPRESSOR
COOLANT OUTLET
TUBE BUNDLE
LIQUID REFRIGERANT FROM RECEIVER
BAFFLE
COOLANT INLET

EVAPORATOR SHELL AND TUBE TYPE

Fig. XI-C-1-5

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of a metering device in a refrigeration system.
2. Be able to identify the various types of metering devices.

Information: The purpose or function of any metering device will be the same regardless of which type is used. It must accomplish two things:

1. It must meter or control the rate of flow of the liquid refrigerant to the evaporator. The flow rate must be equal to the rate of evaporation taking place in the evaporator.
2. It must establish and keep a pressure differential between the high- and low-pressure side of the system. This is necessary so that the refrigerant can vaporize at the desired low pressure in the evaporator and be condensed in the condenser at a high pressure.

There are three basic types of metering devices or flow control devices:

1. Expansion valves
2. Float valves
3. Capillary tubes

Expansion valves fall into two catagories:

1. Hand
2. Automatic

The hand expansion valve (Figure XI-D-1-1) is a needle valve that is manually operated. The amount of liquid that passes through the valve will depend on the valve opening and the pressure differential across the valve orifice. The main disadvantage is that it can not respond to load changes in the system. Any load change requires a manual adjustment which requires an operator's evaluation. This of course can cause a wide variety of changes depending on just how sharp the operator is.

The automatic expansion valve (Figure XI-D-1-2) is made up of a needle and seat, a diaphragm or pressure bellows and a spring. The spring tension is adjustable and is set to maintain the pressure desired in the evaporator. This constant pressure is achieved by two opposing forces. The evaporator pressure on the diaphragm causes the valve to try to close and the spring pressure opposing this force causes the valve to try to open. This valve is pressure actuated. There is also another type of automatic expansion valve commonly called a thermostatic expansion valve.

Float valves are often found in a flooded evaporator system. They are classified according to where they are found in the system. The low-pressure float control valve (Figure XI-D-1-3) is on the low-pressure side of a flooded system and controls the evaporator liquid level directly. The high-pressure float control valve (Figure XI-D-1-4) controls the evaporator liquid level indirectly. They can be used on a dry expansion type evaporator as shown in Figure XI-D-1-4 or in a flooded type evaporator system.

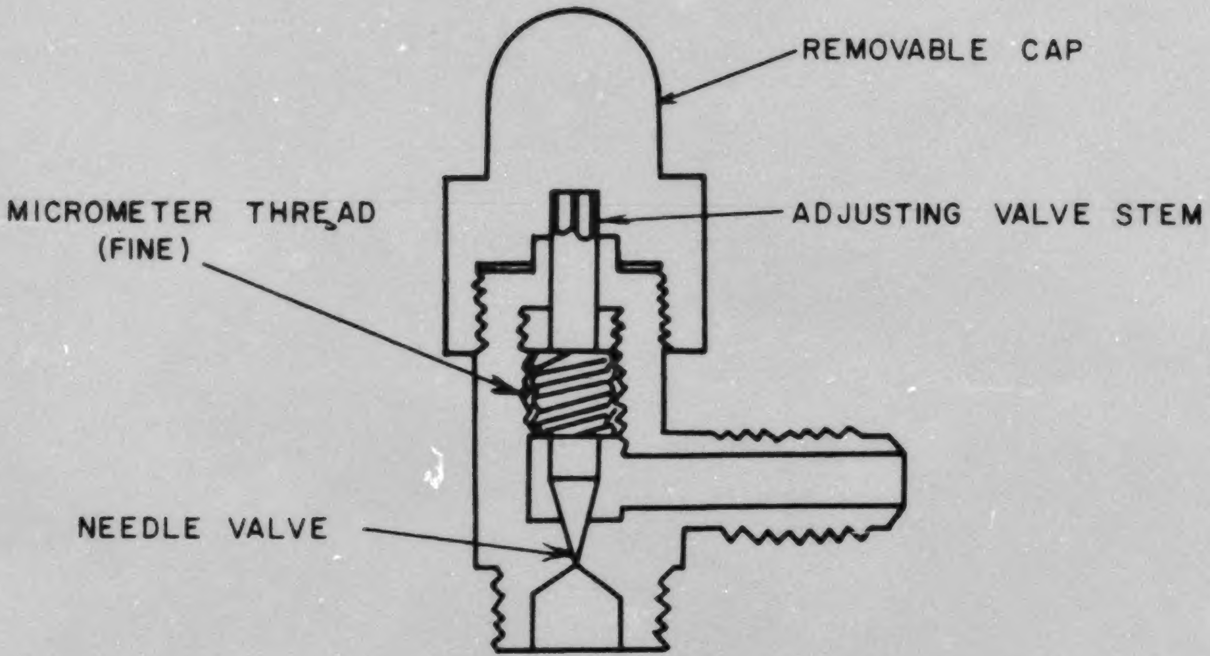
The capillary tube (Figure XI-D-1-5) is probably the simplest refrigerant flow control. It is located between the condenser and the evaporator, and it consists of a small-diameter tubing of fixed length. The capillary tube because of its size restricts the flow of refrigerant from the condenser. This controls the necessary operating pressure differential between the condenser and evaporator. Design plays a big part in the proper operation of the capillary tube. If the tube is too long or too short, too big in diameter or too small in diameter, the flow of refrigerant will be affected and the system will not operate properly.

Reference: *Principles of Refrigeration*, Dossat

Procedure: Study the information and listed reference; then do the following assignment and be prepared to discuss it in class.

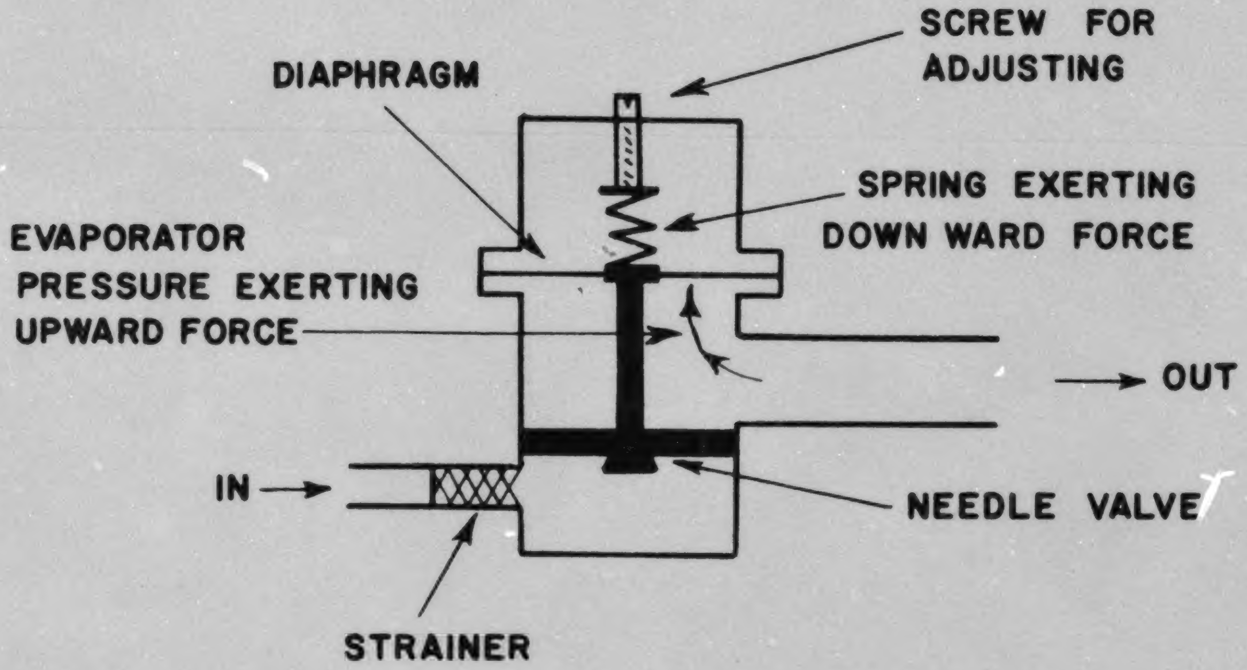
Assignment:

1. What is the function of metering devices in a refrigeration system?
2. What is the main disadvantage of a hand-controlled expansion valve?
3. How is constant pressure achieved in an automatic expansion valve?
4. What type of system would a low-pressure float control valve be found in? Where is it located in the system?
5. Briefly describe where a capillary tube is found in the system and on what principle it operates.


REMOVABLE CAP
MICROMETER THREAD
(FINE)
ADJUSTING VALVE STEM
NEEDLE VALVE

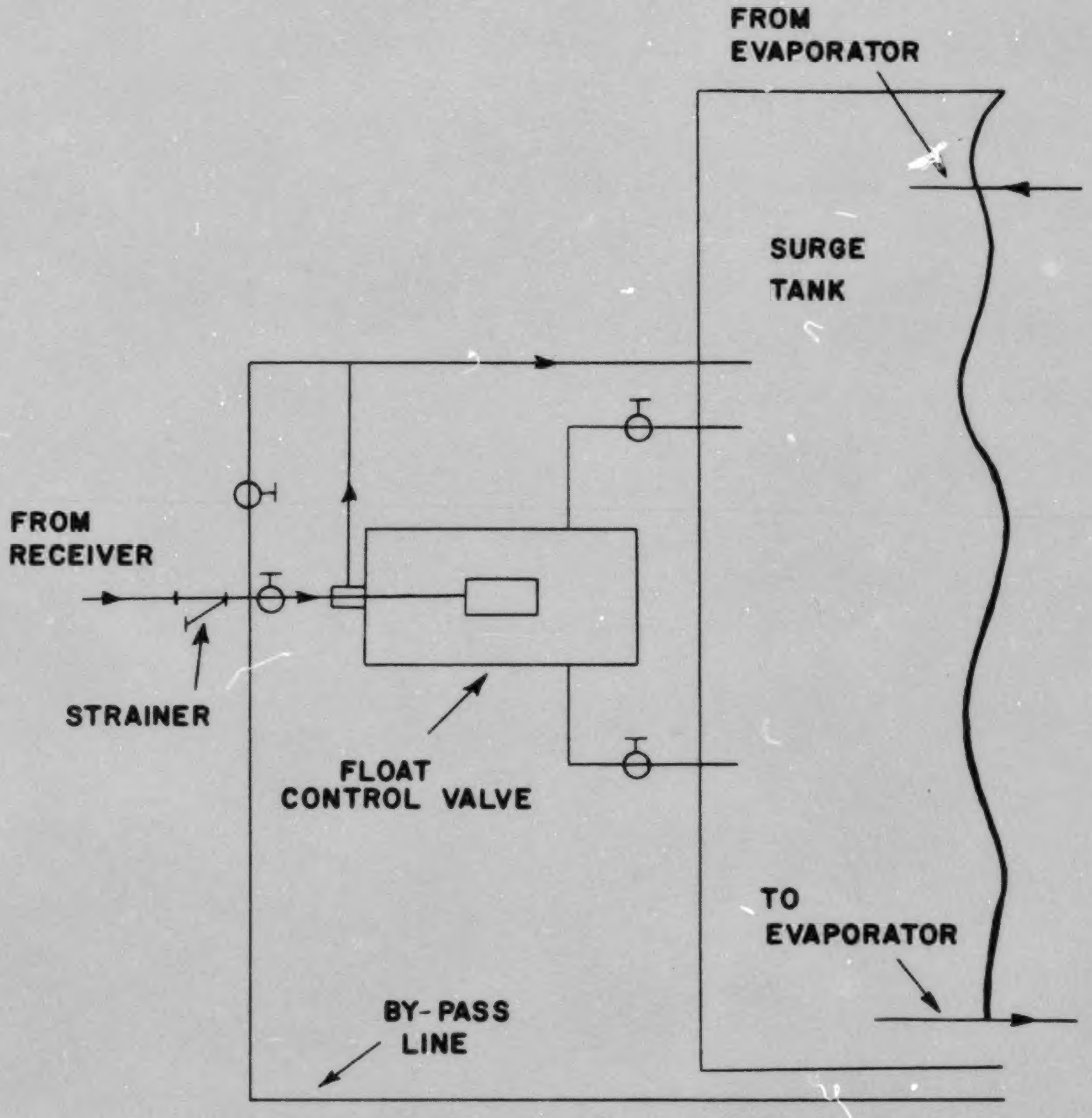
HAND EXPANSION VALVE

Fig. XI-D-1-1


SCREW FOR ADJUSTING
DIAPHRAGM
SPRING EXERTING DOWN WARD FORCE
EVAPORATOR PRESSURE EXERTING UPWARD FORCE
OUT
IN
NEEDLE VALVE
STRAINER

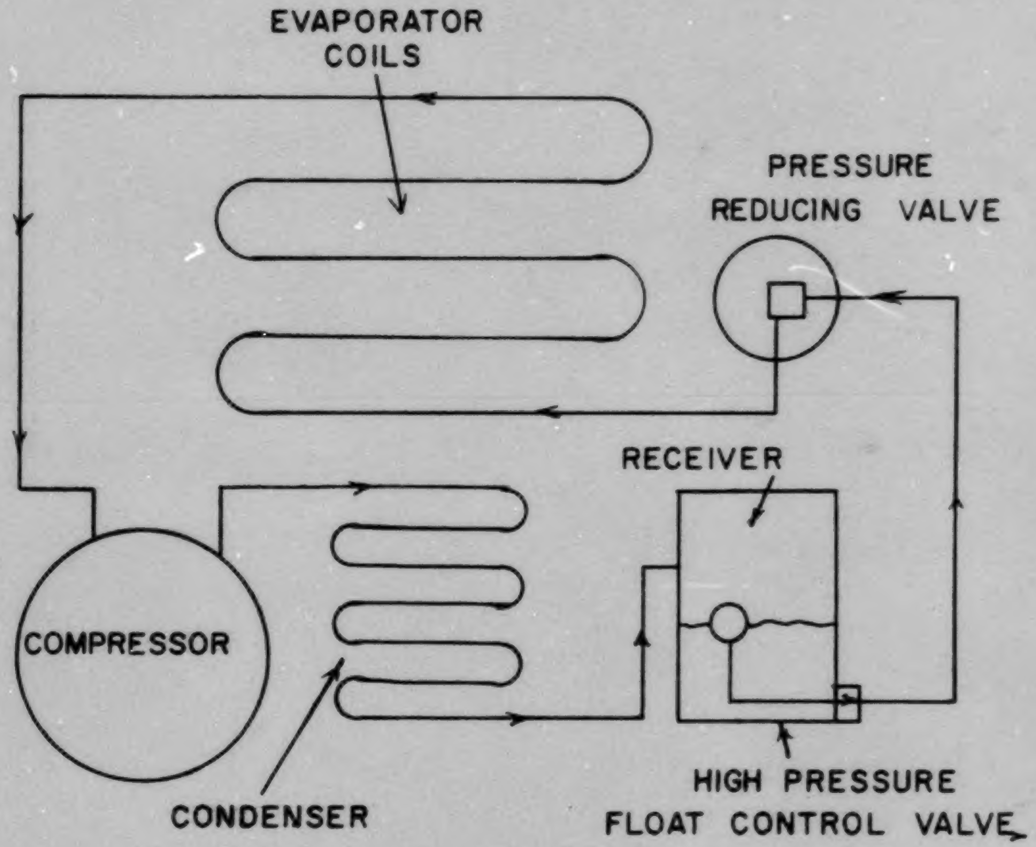
AUTOMATIC EXPANSION VALVE

Fig. XI D-1-2


FROM
EVAPORATOR
SURGE
TANK
FROM
RECEIVER
STRAINER
FLOAT
CONTROL VALVE
TO
EVAPORATOR
BY-PASS
LINE

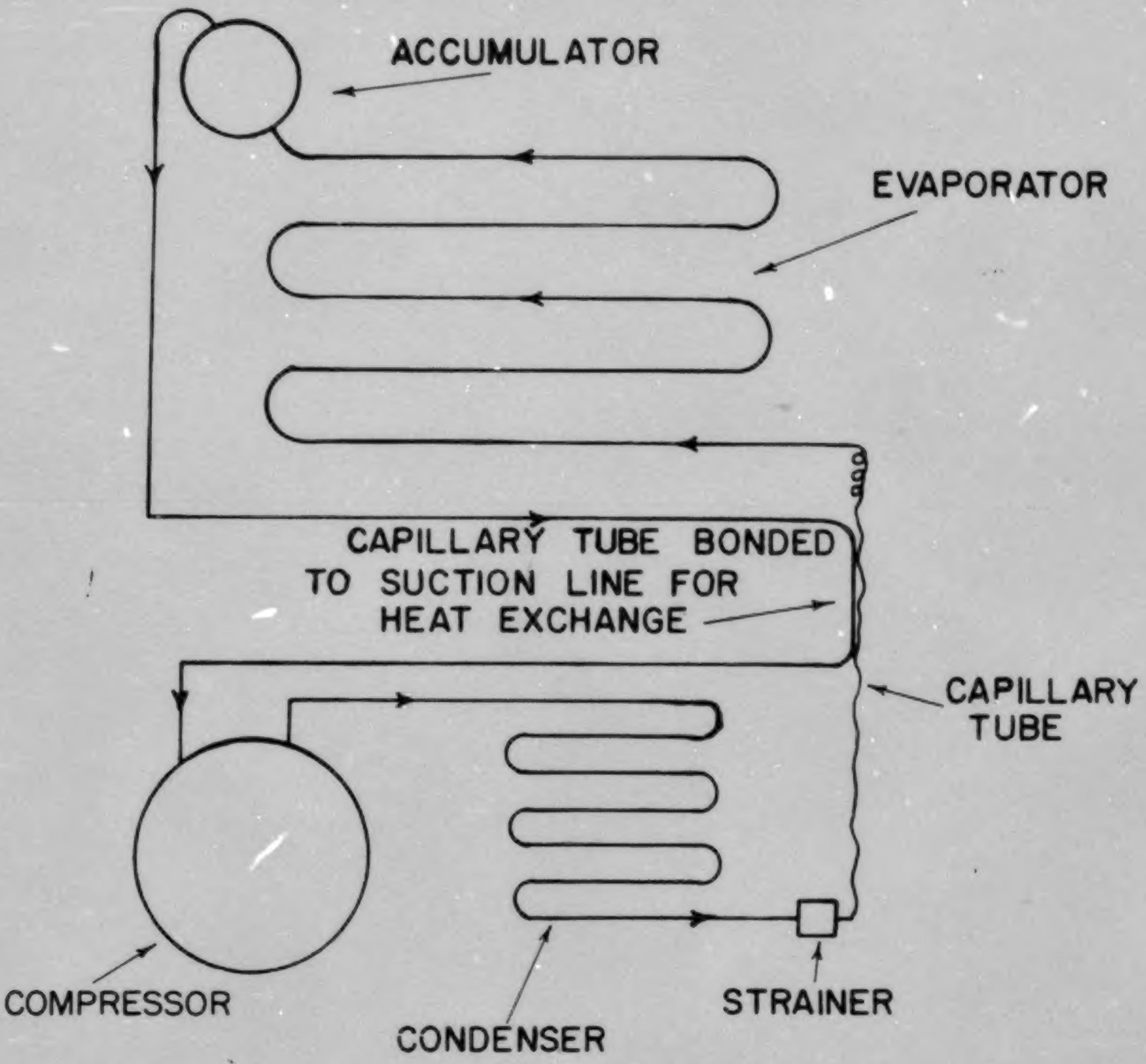
SCHEMATIC
FLOAT CONTROL VALVE

Fig. XI D-1-3


EVAPORATOR COILS
PRESSURE REDUCING VALVE
RECEIVER
COMPRESSOR
CONDENSER
HIGH PRESSURE FLOAT CONTROL VALVE

HIGH PRESSURE FLOAT CONTROL VALVE

Fig. XI-D-1-4


ACCUMULATOR
EVAPORATOR
CAPILLARY TUBE BONDED TO SUCTION LINE FOR HEAT EXCHANGE
CAPILLARY TUBE
COMPRESSOR
CONDENSER
STRAINER

CAPILLARY TUBE

Fig. XI-D-1-5

Objectives: Upon completion of this lesson, the student will:

1. Know the location of the generator in the absorption system.
2. Know the function and operation of a generator.
3. Be familiar with the construction and types of generators.

Information: The generator represents a major component in the absorption-refrigeration system. It converts the refrigerant in a solution to a vapor at a high pressure. This is due to a temperature rise from an external heat source, which absorbs latent heat.

The generator receives the strong solution (refrigerant plus absorbent) from the absorber by means of a pump. It is equipped with some means of heating the solution, usually a steam or hot water coil immerged in a strong solution. As the solution is heated, refrigerant vapor is driven off leaving behind a weak solution of absorbent. The weak solution gravitates to the bottom of the generator. The bottom of the generator is connected by a return pipe to the absorber. Thus the generator is the source of weak solution used in the absorber to absorb the refrigerant vapor as it comes from the evaporator.

Because the generator is under high pressure and the absorber is under low pressure, a pressure-reducing valve is required in the weak solution line to maintain a pressure differential between the two. The refrigerant vapor passes from the generator to the condenser.

The design and construction of a generator may vary according to the manufacturer. Basically the generator is a shell and tube type heat exchanger. The strong solution passes into the shell. A tube assembly containing some heating medium (steam or hot water) passes through the inside of the tubes and heats the strong solution. Some manufacturers contain the condenser and generator within one shell.

References:

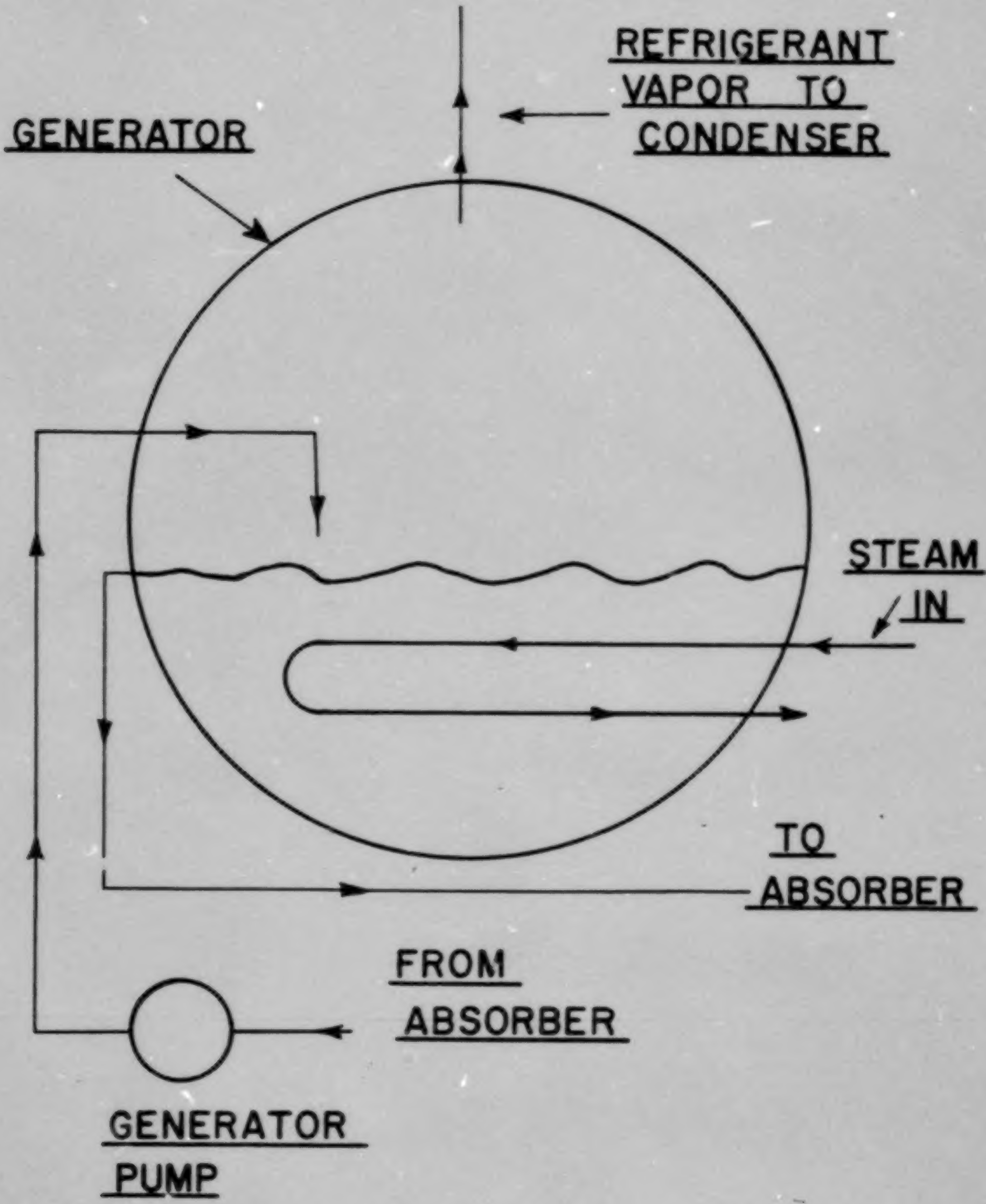
1. *Principles of Refrigeration*, Dossat
2. *Refrigeration, Air Conditioning, and Cold Storage*
3. Manufacturers' data sheets and catalogs

Procedure: Study the information and listed references; then do the following assignment and be prepared to discuss it in class.

Assignment:

1. Explain where the generator is located in the system.
2. What is the purpose of the generator?
3. How is the strong solution heated? Where does the heating medium come from? Explain.

4. What happens to the refrigerant vapor in the generator?
5. Explain the term *weak solution.*
6. Explain the term *strong solution.*
7. Describe the construction and design of a generator.


GENERATOR
REFRIGERANT VAPOR TO CONDENSER
STEAM IN
TO ABSORBER
FROM ABSORBER
GENERATOR PUMP

GENERATOR

Fig. XI-E-1-1

CONDENSER AND GENERATOR

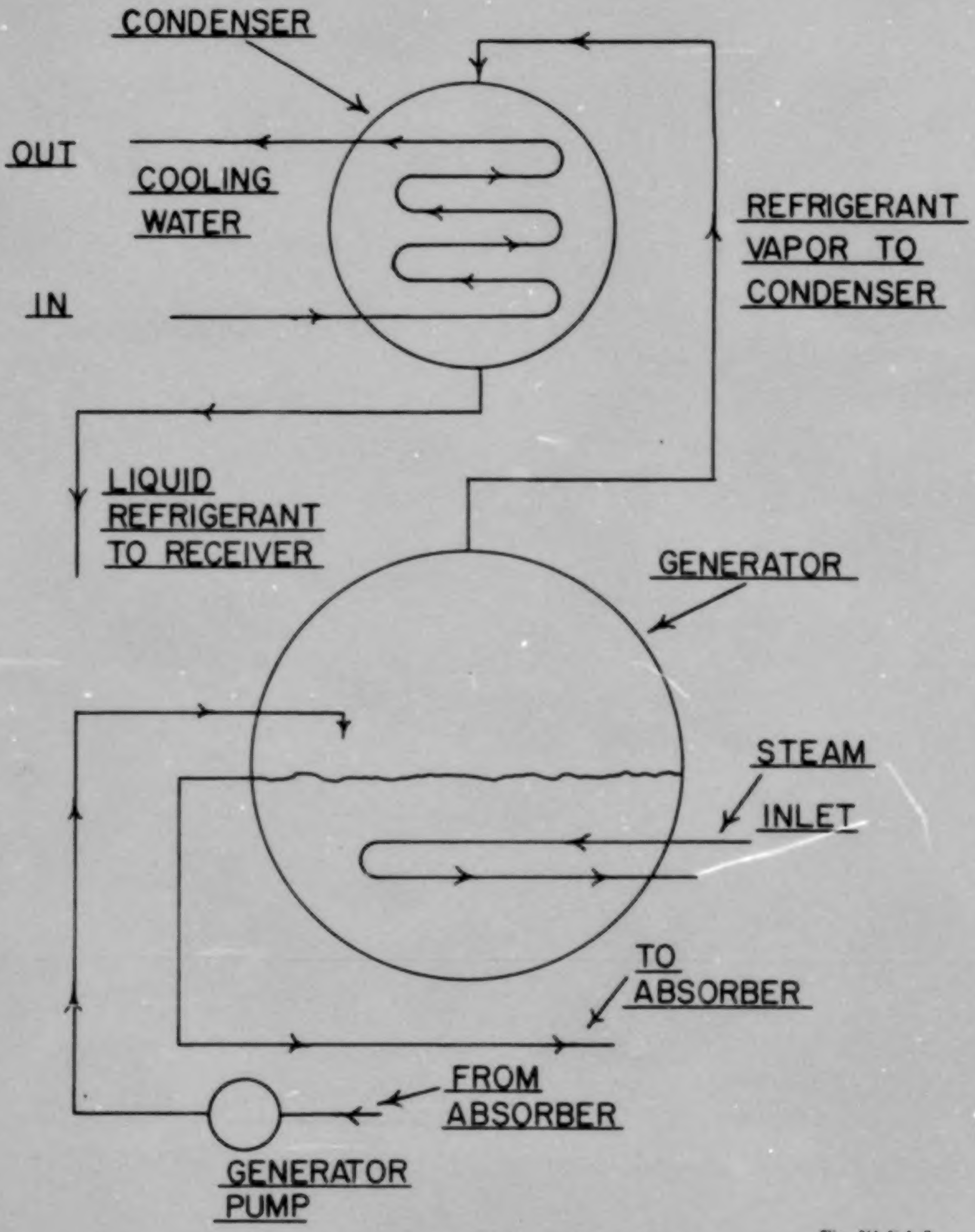

CONDENSER
OUT
COOLING WATER
IN
REFRIGERANT VAPOR TO CONDENSER
LIQUID REFRIGERANT TO RECEIVER
GENERATOR
STEAM
INLET
TO ABSORBER
FROM ABSORBER
GENERATOR PUMP

Fig. XI-E-1-2

Objectives: Upon completion of this lesson, the student will:

1. Know the location of the absorber.
2. Know the function and operation of an absorber.
3. Be familiar with the construction and types of absorbers.

Information: The absorber is located on the low-pressure side of the system, which corresponds to the suction side of the compressor in a compression-type refrigeration system. The absorber receives the refrigerant vapor from the evaporator, where it has produced its refrigerating effect. The absorber is a separate component in which a weak solution of absorbent is sprayed. As the vapor from the evaporator enters the absorber, it is absorbed by the weak solution. During the process of absorption, the following occurs:

1. The weak solution is converted to a strong solution.
2. The temperature of the solution is raised.

Lowering the absorber temperature increases the amount of refrigerant that will go into solution. This is done by circulating water through a coil inside the absorber; this increases the refrigerating capacity of the unit.

The construction and design of the absorber is basically a tube and shell type heat exchanger. The refrigerant vapor flows into the shell from the evaporator. The weak solution of the absorbent is sprayed into the absorber through a spray header. The weak solution absorbs the refrigerant vapor. Cooling water flows through a tube bundle on the inside of the shell removing the heat from the solution. Depending upon the manufacturer the absorber can be separate or a part of the evaporator, thereby having one shell for both components.

References:

1. *Principles of Refrigeration*, Dossat
2. *Refrigeration, Air Conditioning, and Cool Storage*
3. Manufacturers' data sheets and catalogs

Procedure: Read the information, study the listed references, do the following assignment, and be prepared to discuss it in class.

Assignment:

1. Where is the absorber located in the system?
2. Describe the construction and design of an absorber.
3. What is the purpose of the cooling water in the absorber?
4. How does the cooling water help to increase the capacity of the unit?
5. What two substances come together in the absorber? What is the effect on each of the two substances?

ABSORBER

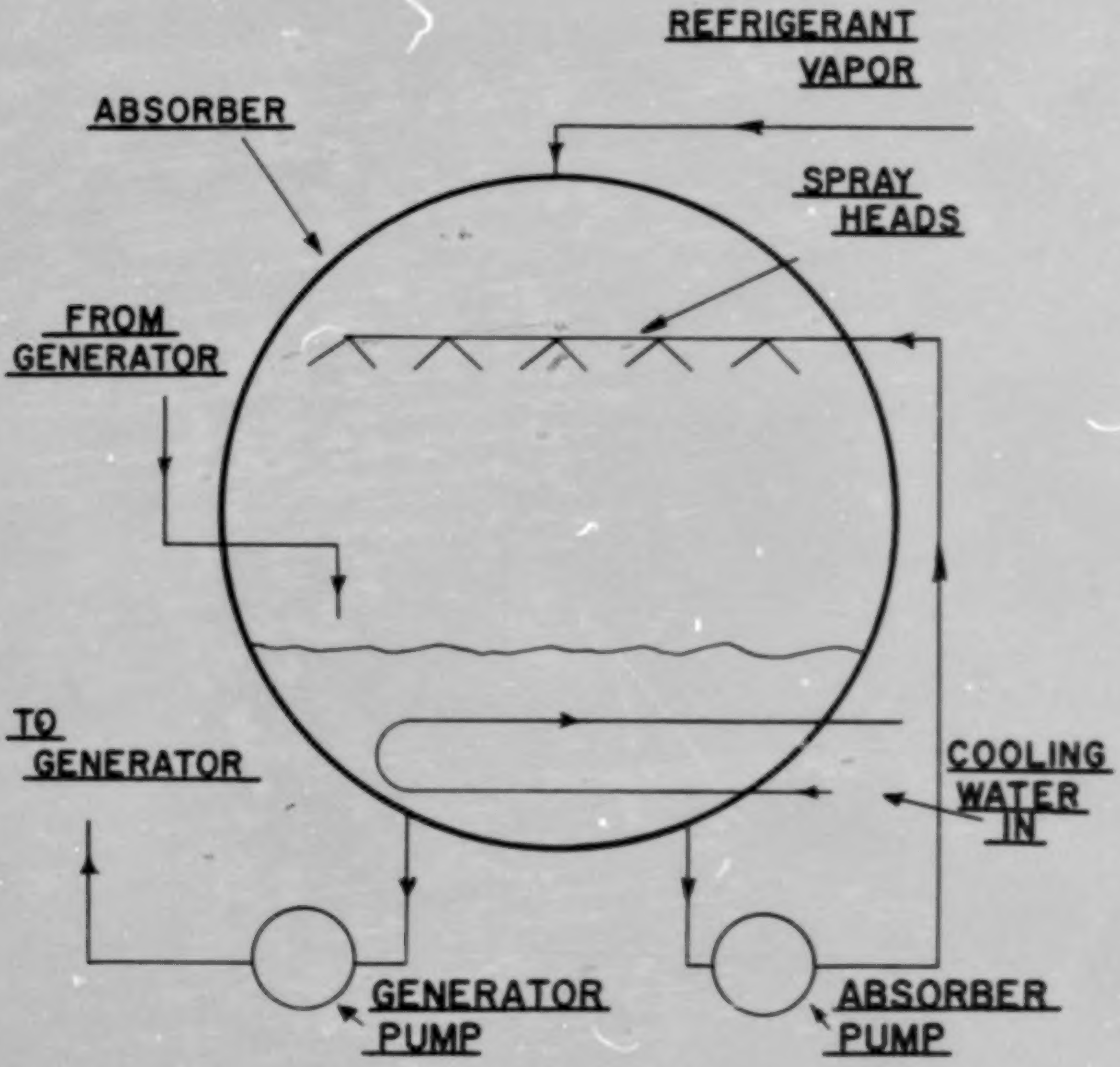

REFRIGERANT VAPOR
ABSORBER
SPRAY HEADS
FROM GENERATOR
TO GENERATOR
COOLING WATER IN
GENERATOR PUMP
ABSORBER PUMP

Fig. XI-F-1.1

Solenoid Valves — Assignment XI-G-1

Objectives: Upon completion of this lesson, the student will:

1. Know how a solenoid valve operates.
2. Know where and why they are used in the refrigeration system.
3. Know the two basic types of solenoid valves and where they are used.

Information: A solenoid valve is an automatic valve that is operated electrically. They are widely used in the refrigeration system on water lines, brine lines, and refrigerant lines because of their automatic operation.

Solenoid valves fall into two basic categories:

1. Direct acting
2. Pilot operating

Figure XI-G-1-1 shows a solenoid valve de-energized, or in its closed position, and Figure XI-G-1-2 is in its energized or open position. Figure XI-G-1-3 shows a pilot-operated valve. It operates as follows: When the solenoid coil is energized, it pulls the plunger (1) up into the coil (2) thus opening the pilot port (3). This will cause the pressure on top of the floating main piston (4) to flow through the open pilot port. This causes a pressure unbalance across the piston: the higher pressure under the piston then forces it to move upward which opens the main valve port (5).

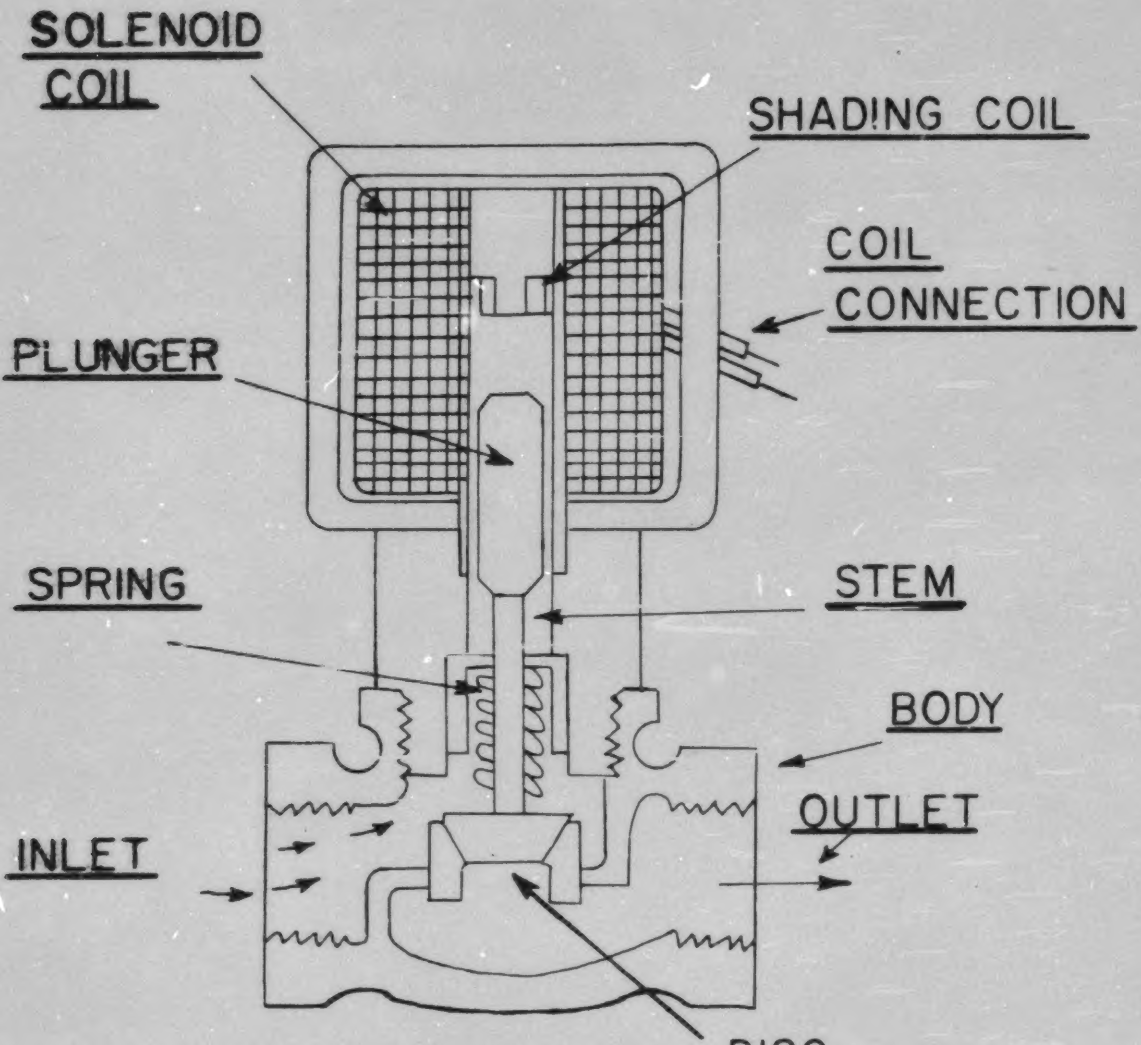
When the solenoid valve is de-energized, the plunger drops,closing the pilot port. This causes the pressure to build up on top of the main piston which drops and closes off the main valve port.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After having studied the sketches, information, and references, do the following assignment and be prepared to discuss it in class.

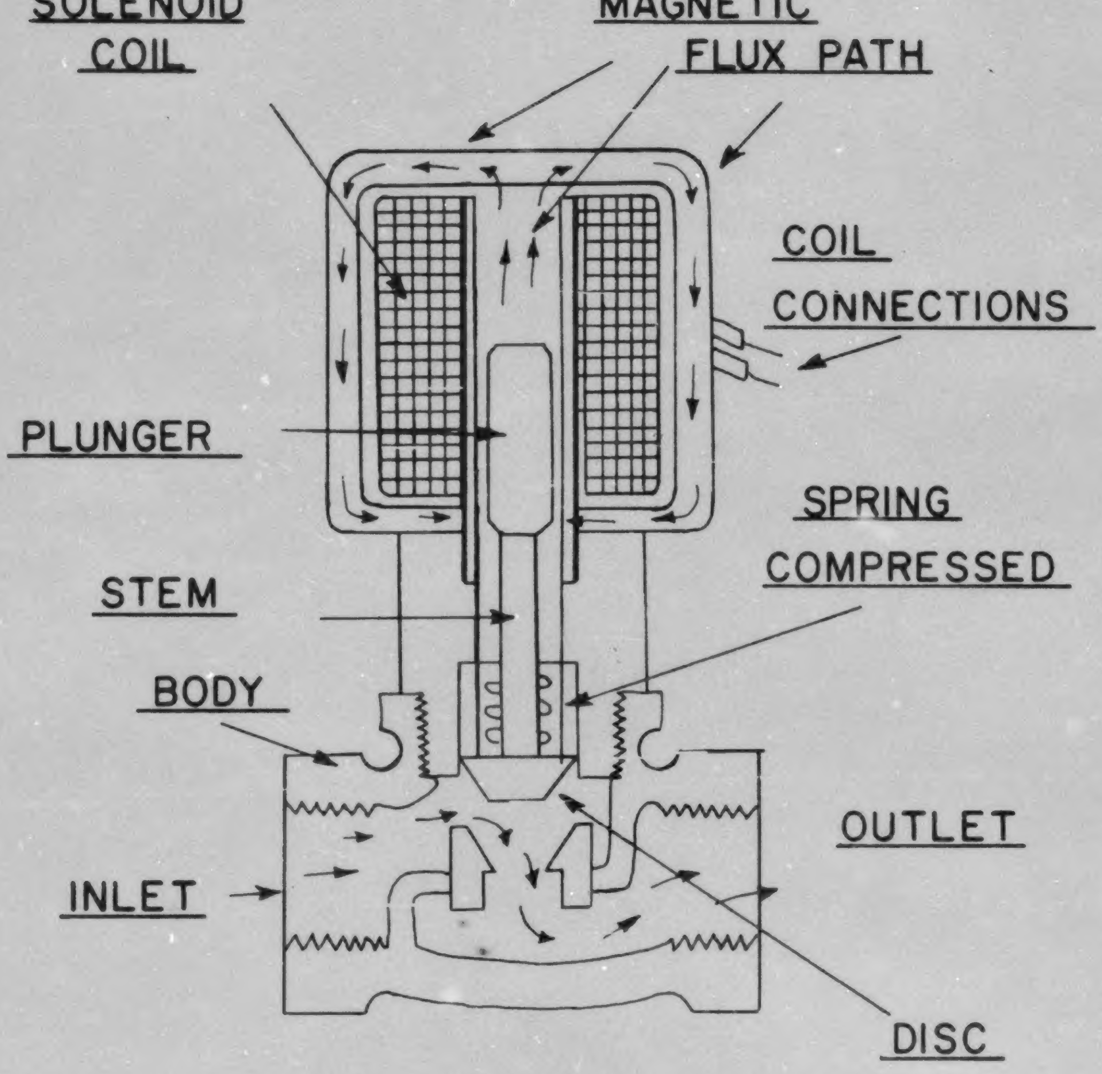
Assignment:

1. Why do you think solenoid valves are so widely used in refrigeration systems?
2. What is meant by a *direct-acting* solenoid valve?
3. What type of application are direct-acting solenoid valves used on?
4. What is meant by a pilot-operated valve?
5. What type of application are pilot-operated valves used on?


SOLENOID COIL
SHADING COIL
COIL CONNECTION
PLUNGER
SPRING
STEM
BODY
OUTLET
INLET
DISC

DE- ENERGIZED

Fig. XI-G-1-1


SOLENOID COIL
MAGNETIC FLUX PATH
COIL CONNECTIONS
PLUNGER
SPRING COMPRESSED
STEM
BODY
OUTLET
INLET
DISC

ENERGIZED

Fig. XI-G-1-2

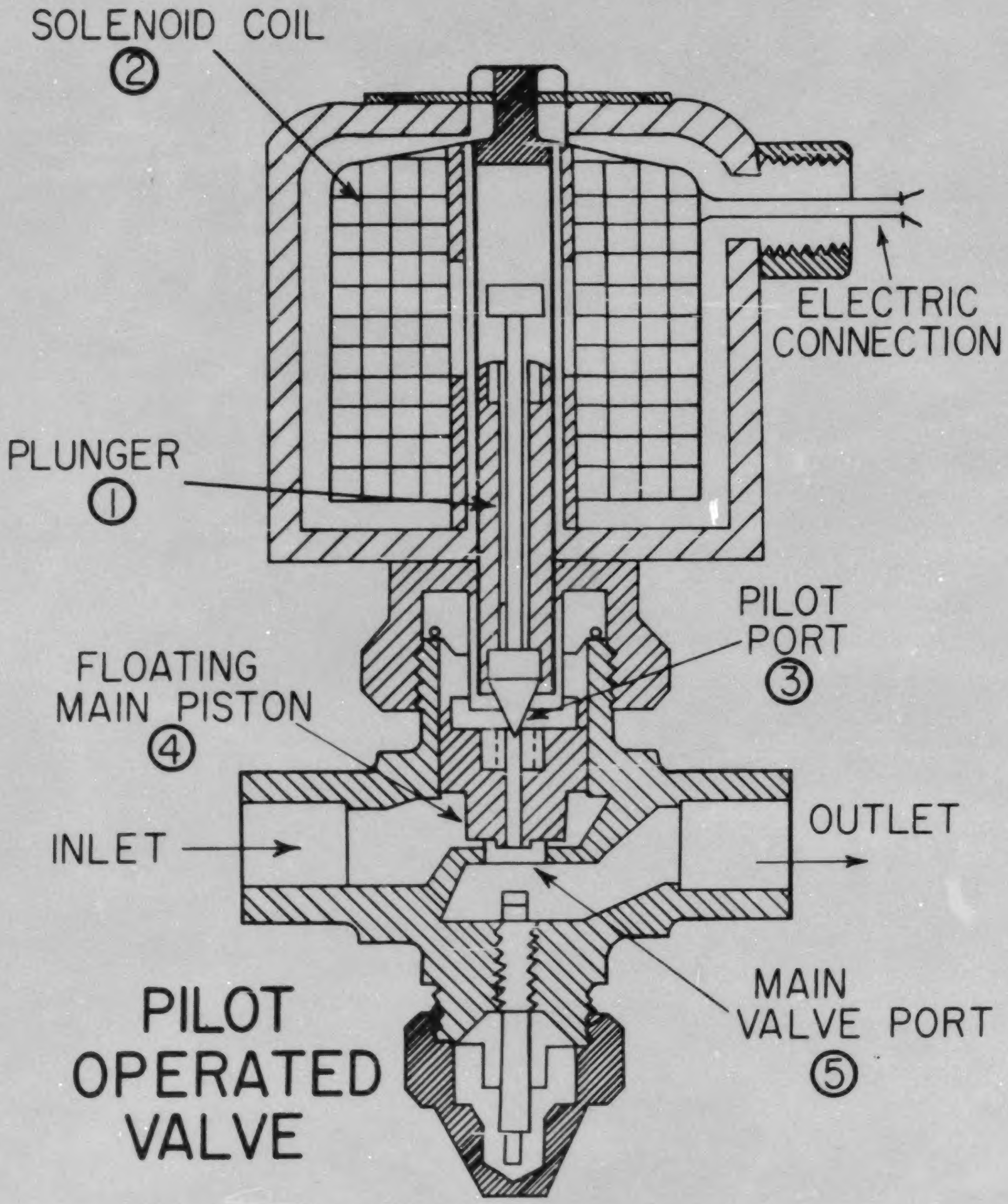

SOLENOID COIL
②
ELECTRIC
CONNECTION
PLUNGER
①
PILOT
PORT
③
FLOATING
MAIN PISTON
④
INLET
OUTLET
MAIN
VALVE PORT
⑤
PILOT
OPERATED
VALVE

Fig. XI-G-1-3

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of suction-line regulators.
2. Know how suction-line regulators work.
3. Know the application of suction-line regulators

Information: Trade terminology is important. As we discuss suction line regulators, you will notice that these regulators are referred to by more than one name.

The suction-line regulators are divided into categories:

1. Suction-pressure regulator, or holdback valve, or crankcase- pressure regulator.
2. Evaporator-pressure regulator, or evaporator-pressure regulator valve.

The suction-pressure regulator, Figure XI-G-2-1, regulates the downstream or suction pressure at the compressor no matter how high the pressure in the evaporator rises due to increased evaporator load. This is necessary so that the compressor drive is protected from overload during periods of abnormally high evaporator pressure. They are recommended for systems that may be subjected to:

1. High starting loads.
2. Suction-pressure surges.
3. Suction-pressure high due to hot gas defrosting or reverse cycle operation.
4. Operating at excessive suction pressure for long periods of time.

Usually the small suction-line regulators will be direct-acting or internal pilot-operated. The larger sizes that must be more sensitive are external pilot-operated.

The evaporator pressure regulator, Figure XI-G-2-2, regulates the upstream or evaporator pressure. It will prevent the evaporator pressure and temperature from falling below its predetermined minimum setting no matter how low the pressure falls in the suction line because of the compressor. The evaporator pressure regulator will maintain a constant pressure in the evaporator; it will also limit the minimum pressure in the evaporator. They are used in systems that require evaporator pressures or temperatures to be maintained above certain minimums. You will find them used on water and brine chillers to prevent freeze-ups during minimum loading periods. Another application will be air cooling systems that need close humidity control. thus requiring minimum evaporator temperatures.

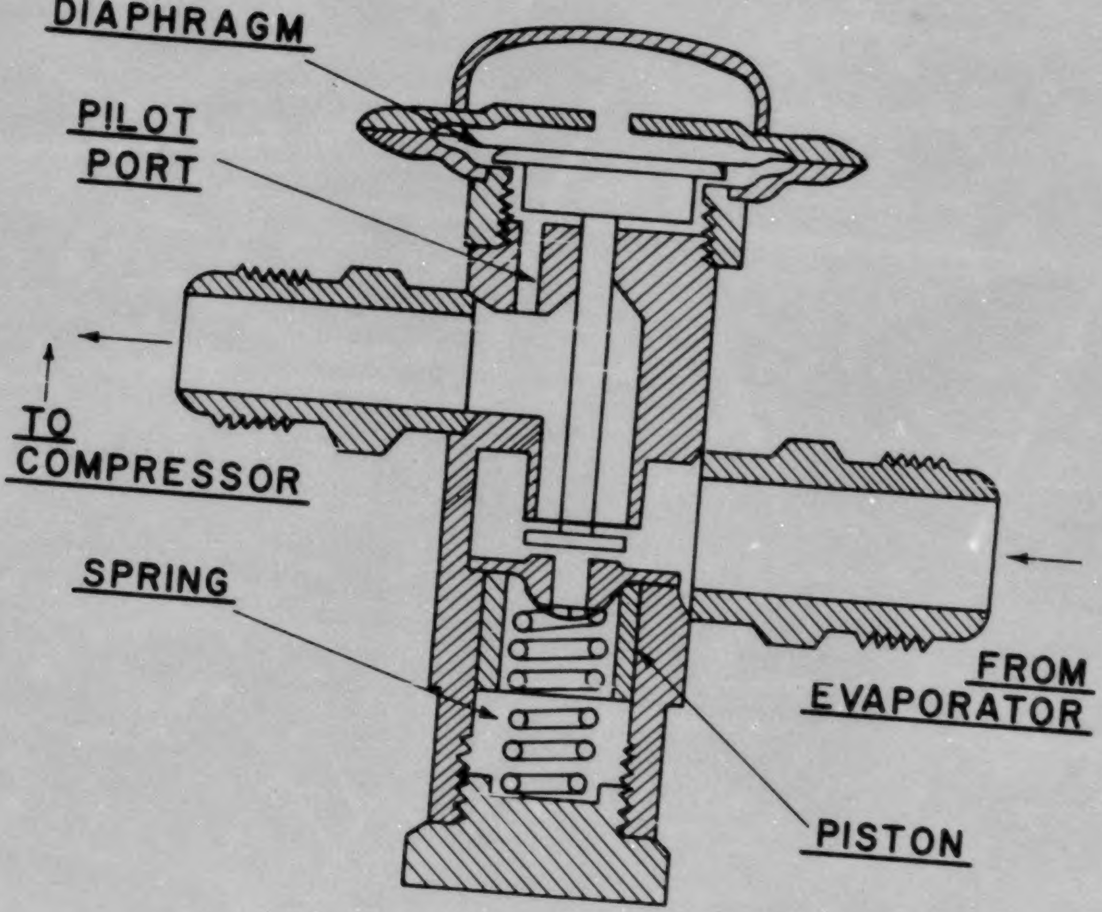
The evaporator-pressure regulator valves may be used on any refrigeration installation requiring a minimum evaporator pressure or temperature regardless of the type of metering valve used. They could be a thermo-expansion, high-side or low-side float, or solenoid liquid valves.

Reference: *Principles of Refrigeration*, Dossat

Procedure: After having studied the information and listed reference, do the following assignment and be prepared to discuss it in class.

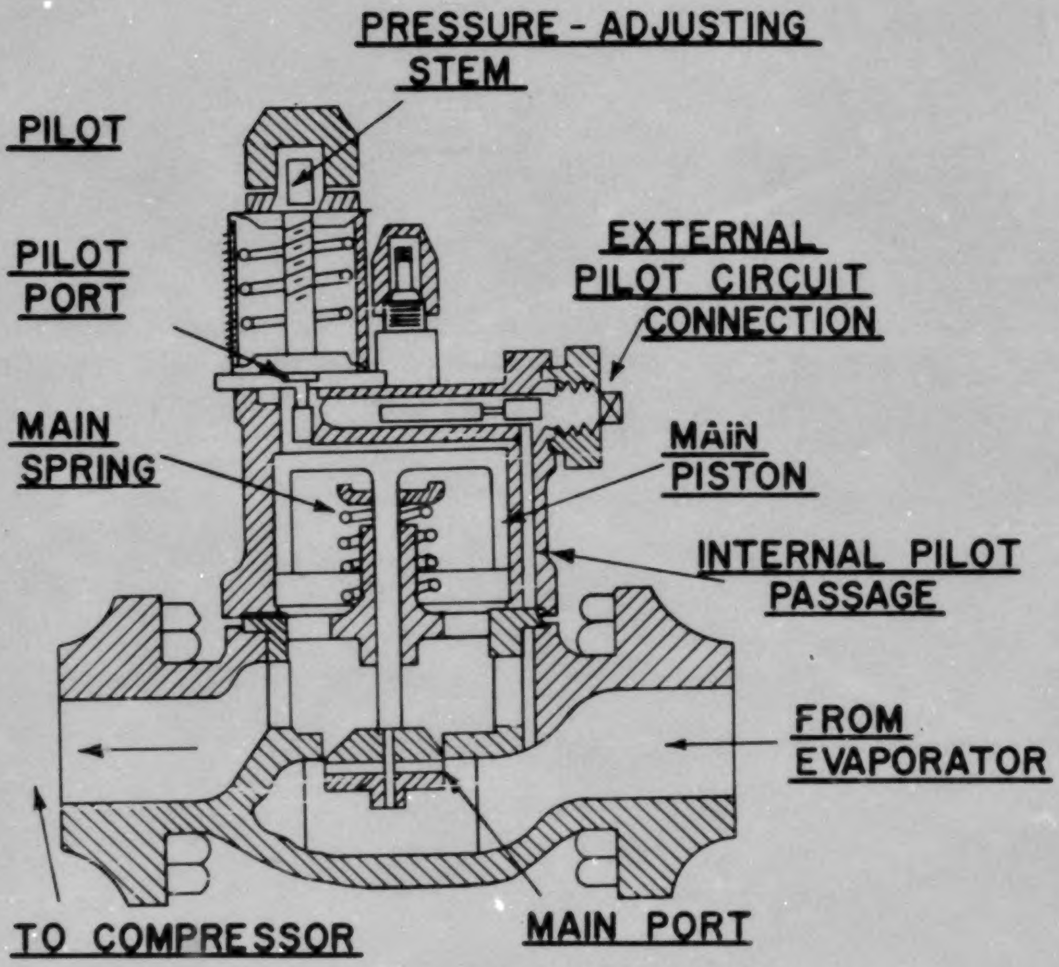
Assignment:

1. Where is a suction-pressure regulator found in the system?
2. What purpose does a suction-pressure regulator valve serve?
3. Under what conditions would you recommend a suction-pressure regulator valve?
4. Where is an evaporator-pressure regulator found in the system?
5. What purpose does an evaporator-pressure regulator valve serve?
6. What are some of the applications that require an evaporator-pressure regulator valve?


DIAPHRAGM
PILOT PORT
TO COMPRESSOR
SPRING
FROM EVAPORATOR
PISTON

SUCTION-PRESSURE
REGULATOR

Fig. XI-G-21


PRESSURE - ADJUSTING STEM
PILOT
PILOT PORT
EXTERNAL PILOT CIRCUIT CONNECTION
MAIN SPRING
MAIN PISTON
INTERNAL PILOT PASSAGE
FROM EVAPORATOR
TO COMPRESSOR
MAIN PORT

EVAPORATOR-PRESSURE REGULATOR
PILOT OPERATED

213 Fig. XI-G-2-2

Objectives: Upon completion of this lesson, the student will:

1. Identify and know the location of the dryer.
2. Know the purpose of the dryer.
3. Know the different types of dryers.

Information: Because of the harmful effects of moisture within a refrigeration system, every precaution should be taken to prevent its entrance or to eliminate it if already present.

Some of the harmful effects of moisture in a system are:

- a. It can combine with certain refrigerants and form corrosive compounds.
- b. It freezes and interferes with the function of expansion valves.
- c. It deteriorates lubricating oil.
- d. It reduces system capacity.

The amount of moisture in the system may be controlled by the use of a suitable dryer. Dryers are cartridge-like units consisting of an outer shell having tube connections at both ends.

The most effective location for a dryer in most systems is in the liquid line between the receiver and the expansion valve. It should be located in the cold compartment if at all possible. The reason for selecting this location is:

- a. The moisture is concentrated in a much smaller volume of fluid when refrigerant is in its liquid state as compared with its vapor state.
- b. It provides better protection for the expansion valve.
- c. The refrigerant travels at its minimum velocity in the liquid line.

The drying material used in refrigerant dryers is called the "desiccant". The desiccant may be molded into a special form to fit a dryer container, or it can be used as granules or in ball form. The drying materials may be divided into two general types referred to as (1) the *adsorption* type and (2) the *absorption* type.

The adsorption type is a physical process whereby the desiccants pick up and hold the moisture. Fluid adheres to the solid surfaces to form a thin film without apparent chemical change in either substance. Because the bond between the desiccant and the moisture is not permanent, reactivation of the material is possible allowing for its re-use. This is accomplished by heating at mild temperatures to drive off the mild moisture collected in the system.

The most commonly used adsorption type materials are silica gel and activated alumina.

The absorption type of desiccant has an affinity for moisture and will react with it to form another compound. These dryers cannot be reactivated; they must be replaced by a fresh charge. This type of dryer must be replaced every 12 to 18 hours and the advantage of using this type is in its ability to absorb moisture rapidly.

References:

1. Manufacturers' data sheets and catalogs.
2. *Refrigeration, Air-conditioning, and Cool Storage*
3. *Principles of Refrigeration*

Procedure: Study the listed references, do the following assignment, and be prepared to discuss it in class.

Assignment:

1. Why must moisture be removed from the system?
2. The desiccant used in a dryer must be capable of doing several things. What are they?
3. What are the two types of dryers?
4. Why are most dryers placed ahead of the expansion valve?
5. Describe the two types of dryers and the material used in them. Explain how they remove the moisture from the system.

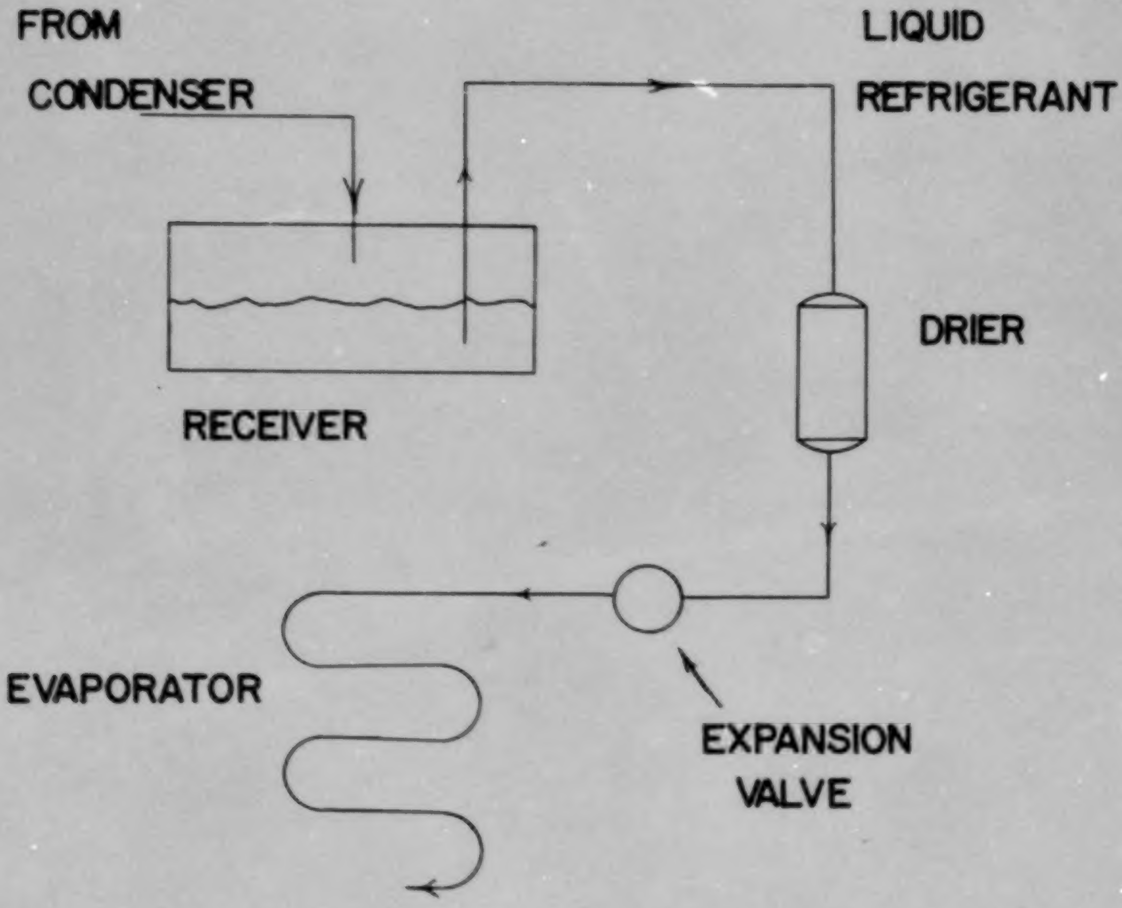

FROM
CONDENSER
LIQUID
REFRIGERANT
RECEIVER
DRIER
EVAPORATOR
EXPANSION
VALVE

Fig. XI-H-1-1

Filters and Strainers

Assignment XI-H-2

Objectives: Upon completion of this lesson, the student will:

1. Identify and locate the filter and strainer.
2. Know the purpose of a filter and strainer.
3. Be familiar with the design and construction of filters and strainers.

Information: Any refrigeration system will accumulate a certain amount of foreign matter that eventually interferes with good operation. Gums, sludge, fibers, waxes, and abrasive particles occur in refrigeration systems, as well as in water, oil, or any other circulating systems. The source of the contamination can be a poor grade or quality of lubricating oil, packing, scale, frictional surfaces including compressors, pumps, and valves. Unless this material is continually removed, proper valve seating, fouled control mechanisms, clogged orifices, and aggravated wear of frictional surfaces will result. The installation of flow-line cleaners such as filters and strainers are used to remove this foreign matter from the system. Filters and strainers are located throughout the system. They are found before dryers or expansion valves and on the suction side of the compressor. The screening ability of any cleaner depends upon the density and depth of the filtering material, or the mesh size of the strainer element. Another important factor is the amount of exposed area and the pressure drop across the cleaning assembly. Strainers are effective in trapping foreign material of relatively small size which would be capable of preventing proper control seating. They are designed for straight-line flow or in the form of a demountable trap. Filters are capable of removing material of microscopic size. They are equipped with fiber filters and are recommended for use in new systems.

References:

1. Manufacturers' data sheets and catalogs.
2. *Refrigeration, Air Conditioning and Cold Storage.*

Procedure: After having studied the material and listed references, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What is the purpose of a strainer in the refrigeration system?
2. Where are strainers located in the system? Why?
3. Describe a filter and trap and discuss design in relation to screening ability.

Liquid Flow Indicator — Assignment XI-H-3

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of a liquid-flow indicator.
2. Know the location of a liquid-flow indicator.

Information: To determine the amount of liquid flowing through a pipe, liquid indicators are used. Such indicators are installed in the liquid line so that the liquid passes directly through them. Looking through the window of a liquid indicator is the simplest way to determine whether there is a refrigerant shortage. This could be due to leaks in the system or failure to charge enough refrigerant in the system. Liquid indicators are pipe fittings equipped with a sight glass through which the flowing refrigerant may be seen. Partial flow of liquid refrigerant is indicated by a bubbling action. Some indicators are manufactured with double ports which are on opposite sides of the pipe, thus helping the operator see the liquid easier. The indicators are made with either flare or solder connections.

References:

1. Data sheets and catalogs.
2. *Refrigeration, Air Conditioning and Cold Storage*

Procedure: After having studied the listed references and information, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What is the purpose of a liquid-flow indicator?
2. How will a lack of refrigerant be indicated in the sight glass?
3. Where is the indicator located in the system?
4. How can the indicator be attached to the system?

Spray Ponds **Assignment XII-A-1**

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with a spray pond.
2. Understand the theory of operation of a spray pond.

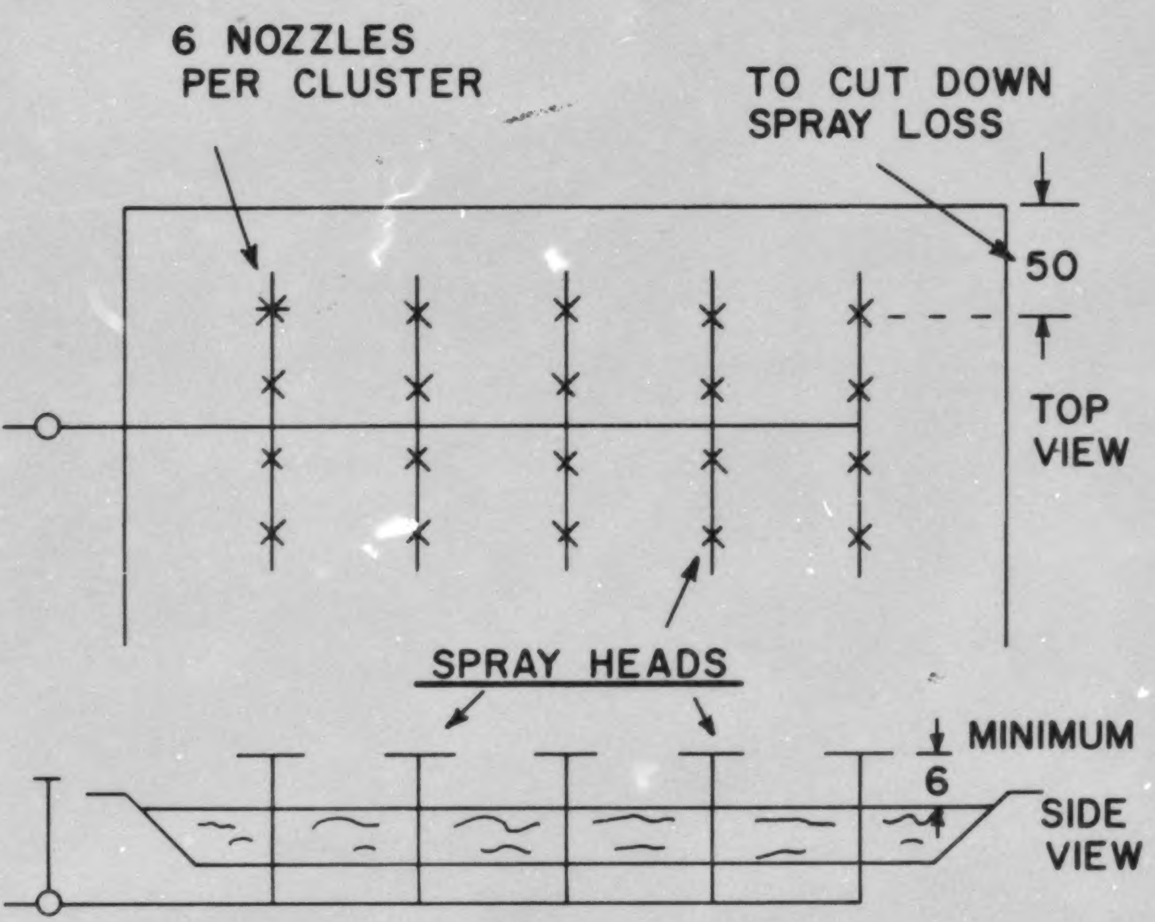
Information: A source of cooling water for power and manufacturing plants can be a spray pond. Spray ponds are used where the plant is not located close to a river or lake and cooling water is required. Heated water is forced through nozzles under pressure ranging from 3 to 15 pounds and is broken up into a number of fine sprays. The nozzle is designed to give a whirling motion producing more atomizing of the water. By breaking the warm water up into a fine mist and exposing it to the evaporation and cooling effect of the atmosphere, the temperature of the water is reduced. This water can now be recirculated through the plant cooling system. Spray cooling systems will reduce the temperature of the water anywhere from 20° to 40° depending on the temperature and humidity of the surrounding air. The depth of the cooling ponds is generally 3 to 4 feet. The depth has little influence on the cooling effectiveness; surface area is the determining factor. A spray pond requires less ground area than a cooling pond. One sq.ft. of surface will take care of 150# of water per hour for a 500 hp plant. Spray ponds are sometimes located on roofs of buildings when ground area is not available.

Reference: *Steam Plant Operation*

Procedure: After having studied the reference and read the information, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Describe a spray pond.
2. What is the purpose of a spray pond?
3. What is the purpose of the cooling water in a recirculating system?
4. List the features required of a good spraying system.
5. Why is it necessary to use a spray nozzle?
6. How much pressure is required on spray pond pipe systems?
7. How much of a temperature drop can you expect using a spray pond?


6 NOZZLES
PER CLUSTER
TO CUT DOWN
SPRAY LOSS
50
TOP
VIEW
SPRAY HEADS
MINIMUM
6
SIDE
VIEW

SPRAY POND

Fig. XII-A-1-1

Cooling Towers – Natural and Mechanical Assignment XII-B-1

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with natural and mechanical cooling towers.
2. Be familiar with the theory of operation of cooling towers.

Information: Whenever there is insufficient water or where water is unsuitable for use in condensers, some type of water recirculating system must be employed. Water cooling towers are used for this purpose and may be classified as follows:

A. Natural draft open or atmospheric type
B. Natural draft closed or flue type
C. Induced draft
D. Combined forced and natural draft

In most cases the water in cooling towers is deliverd to the top of the tower and then permitted to fall to a tank below the tower. The water to be cooled is pumped to the top of the tower to a distribution system of sprays or troughs where the water drains through triangular shaped weirs. The water flows by gravity onto horizontal rows of cypress or redwood breaking into a fine spray. The water is cooled as it falls by gravity through the entire cooling surface to the tank at the base of the tower.

Natural draft open or atmospheric towers are constructed of louvers or slats around the outside with special openings between them.

Natural draft closed or flue type towers are constructed with closed sides and the addition of a considerable height above the portion of the tower containing the cooling surfaces.

Mechanical draft towers have the sides closed forming an air- and water-tight structure and are usually built in units or cells.

The mechanical forced draft tower has a fan at the base of the tower delivering air under pressure to the interior, forcing the air through the outlet at the top of the tower.

The mechanical induced draft tower has a fan located at the top of the tower. The air is drawn in through louvers at the base of the tower. The water to be cooled flows by gravity downward through the tower and is broken into a fine spray. The air passes upward through the tower·the water gives up its heat to the rising column of air by evaporation, convection and radiation.

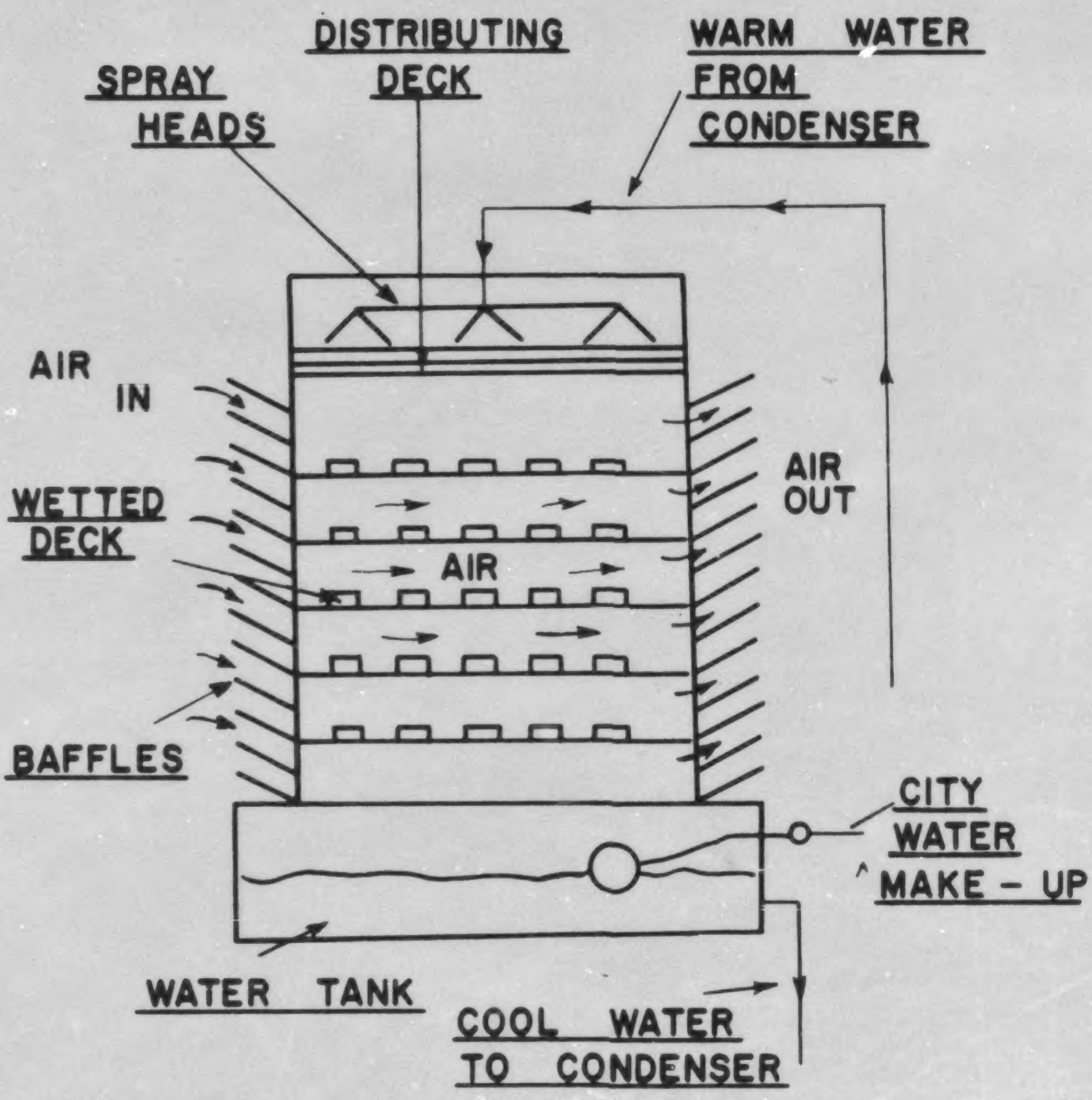
References:

1. *Elementary Steam Power Engineering*
2. *Steam Plant Operation*

Procedure: After having studied the listed references, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What is the principle difference between the spray pond and the cooling tower?
2. Describe and explain how a cooling tower operates.
3. Name the different types of cooling towers and explain how each works.
4. What purpose can the water in the recirculating cycle be used for?
5. What method of heat transfer is used in cooling towers? Explain.


DISTRIBUTING DECK
WARM WATER FROM CONDENSER
SPRAY HEADS
AIR IN
AIR OUT
WETTED DECK
AIR
BAFFLES
CITY WATER ^ MAKE - UP
WATER TANK
COOL WATER TO CONDENSER

NATURAL DRAFT
COOLING TOWER

Fig. XII-B-1-1

Objectives: Upon completion of this lesson, the student will:

1. Know why cooling water is treated.
2. Know how to treat cooling water.

Information: Cooling water in recirculating systems must be chemically treated to remove harmful impurities that may deposit on the internal surfaces of piping machinery and controls. There deposits coat the internal surfaces and interfere with heat transfer thus lowering the capacity and proper operation of the equipment. For scale formation to take place, it is not necessary for the water to be heated to the boiling point. Scale formation can take place at temperatures below 100° F. The two most common types of scale are magnesium carbonate and calcium carbonate. The method of treatment to be used for cooling water will vary according to:

A. The purpose for which it is used.
B. The composition of the water.
C. Whether or not it is to be recovered or reused.

Scale forming impurities can be removed by the use of water softening equipment which will remove these impurities before the water is added to the cooling system. This is sometimes referred to as external treatment. Organic chemicals and compounds are also added to the cooling water. This forms a sludge which is removed by *bleed-off* directly from the bottom of the cooling system. Adding chemicals directly to the cooling water is referred to as *internal-treatment*. The bleed-off is a drain line connected to the cooling water system in which water is continually removed. The amount of bleed-off varies and depends on the size of the unit and the hardness of the water. Corrosion must also be controlled for it can cause metal surfaces to deteriorate causing leakage. In order to control corrosion of the cooling water tower, pipes, controls, and pumps, it is largely a matter of controlling the *pH* value and the amount of oxygen in the water.

Water with a *pH* value of 7 is called neutral. If the pH value is below 7, the water is considered to be acid; above 7, it is alkaline. The determination of the pH value for water is simple and gives an easy method of determining the acidity of cooling water. Coolant water under certain conditions may also form deposits such as algae and other organic growths. In general. copper sulfate and chlorine will be used to combat these conditions. This type of treatment is known as internal treatment.

References:

1. *Steam Plant Operation*
2. Data sheets and catalogs.

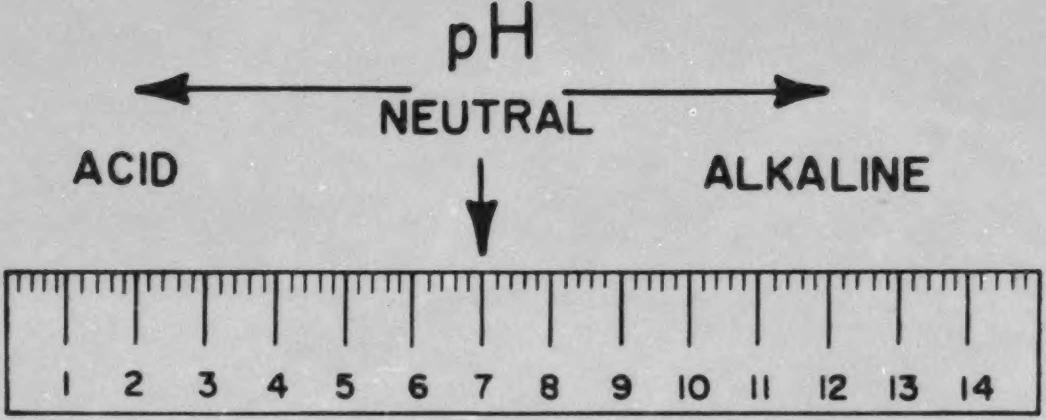


Fig. XII-C-1-1

Procedure: After having read the information and studied the listed references, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Why is chemical treatment of cooling tower water advisable?
2. Why is excessive blow-off uneconomical?
3. What is meant by the pH value of water?
4. What pH reading would you have with neutral water?
5. What would a high pH reading indicate?
6. What type of chemicals are used in cooling water treatment?
7. What is the danger of algae formation?
8. How is algae controlled?

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of a ventilating system.
2. Know the parts of a ventilating system and their function.

Information: The purpose of any ventilating system is to remove foul air and introduce fresh, dust-free, tempered air into a building. Many factors must be considered in the design and layout of a ventilating system. The air being removed must be discharged to the outside in such a manner that it can not be brought back into the building. If toxic fumes are being vented, care must be taken to discharge them so that they do not endanger people working outside or in neighboring buildings. Dust particles must be trapped so that they do not pollute the atmosphere. In order to have a well designed system, some of the following equipment will be used.

A. Intake fans – fans that bring in fresh air.

B. Exhaust fans – fans that remove air and discharge it outside a building.

C. Filters – reusable or throw-away types used to remove dirt and pollen from the air.

D. Dampers – used on both intake and exhaust fans. They can regulate flow of air into a fan and also prevent reversible air flow on exhaust fans.

E. Duct work – air travels through duct work entering and leaving a building. This helps to distribute air where it is needed or wanted.

Ventilating systems that are to be used for schools must conform to state guidelines that are set forth in a book *Guide for Planning School Plants*. In part it states:

> Classrooms – change of 15 cubic feet of air per minute per person
>
> Toilets – six complete air changes per hour. System to be entirely independent of systems servicing the rest of the building.
>
> Classroom and toilet exhaust systems must have separate exhaust ducts and exhaust fans. They must be located in a position high enough to discharge the foul air in such a manner that it cannot gain entrance to any shop or classroom. The following pictures will give you some idea of a school ventilating system.

The classroom exhaust fan (Fig. XIII-A-1-1) suctions air from all classrooms (Fig. XIII-A-1-2), shops (Fig. XIII-A-1-3), and lockers in the corridors (Fig. XIII-A-1-4). The foul air is discharged through large louvers located on the building roof (Fig. XIII-A-1-5). You will notice the louvers are closed in the picture. They are air controlled so that they close when the fan is not in use to prevent a back draft from high winds.

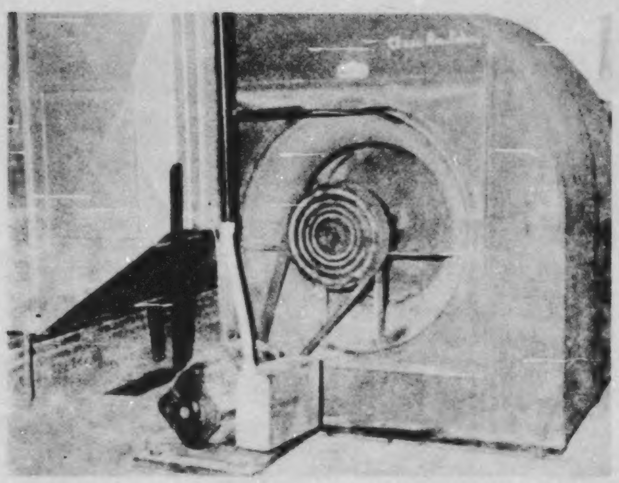


Fig. XIII-A-1-1
Classroom Exhaust Fan Duct Work at upper left leads to discharge louvers.

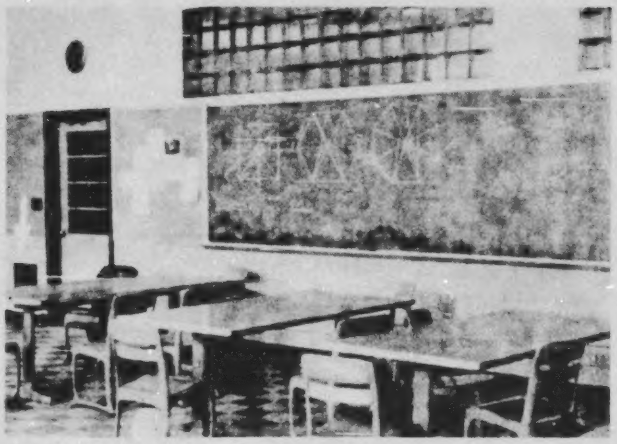


Fig. XIII-A-1-2
Typical Classroom Duct located at lower left side of door.

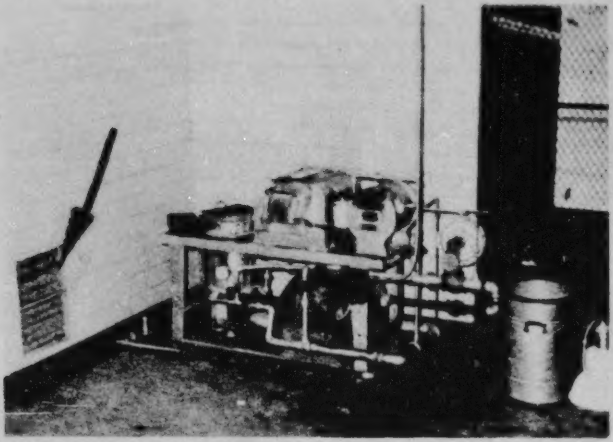


Fig. XIII-A-1-3
Typical Shop
Duct located at lower left.

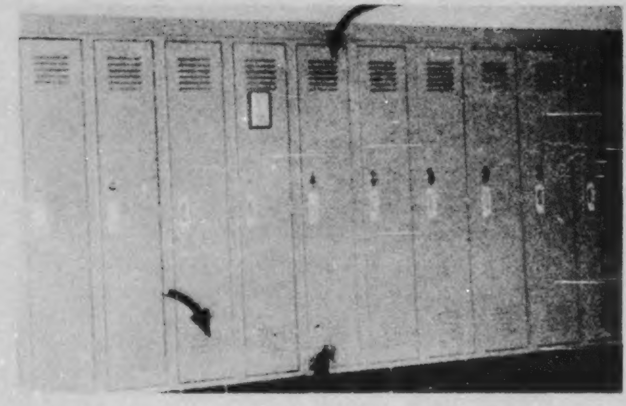
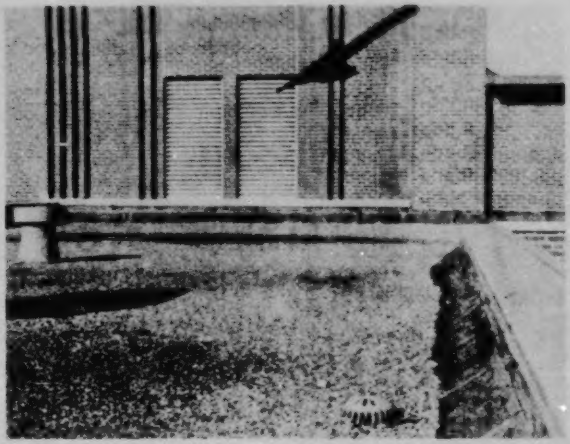


Fig. XIII-A-1-4
Ducts under lockers in corridors.

Fig. XIII-A-1-5
Large louvers which discharge foul air from classrooms and shops.



The toilet exhaust fan, Fig. XIII-A-1-6, has separate duct work leading from all the lavatories in the building. It will discharge the air from the highest point of the building so that there is no chance of foul air re-entering the building.

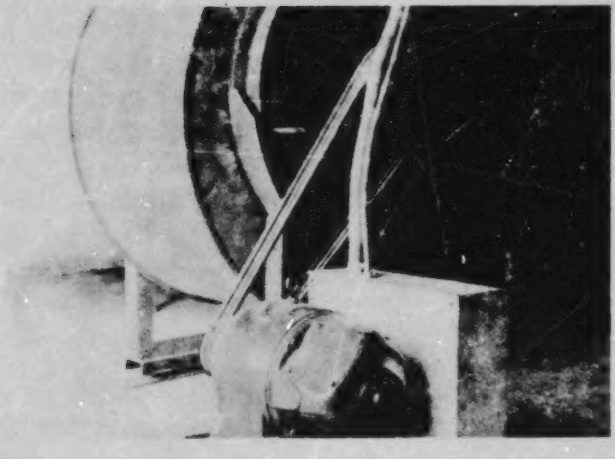


Fig. XII-A-1-6
Separate fan and duct work leading from lavatories

Fig. XIII-A-1-7 is a special fan located on the roof. It is connected by duct work to the hood over the range in the kitchen where it removes heat and cooking odors.

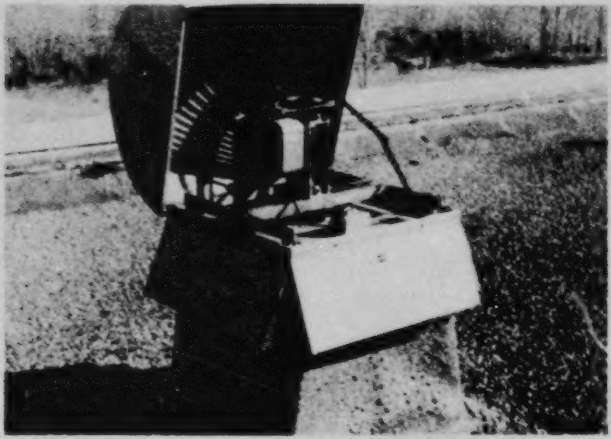


Fig. XIII-A-1-7
Special fan connected by duct work
to range hood in kitchen..

Reference: Manufacturers' data sheets and catalogs.

Procedure: After having studied the information and listed references do the following assignment and be prepared to discuss it in class.

Assignment:

1. Why do you think it is important to be able to handle the movement of air?
2. Do you think it essential to use filters in a ventilating system?
3. What would happen if the filters were not cleaned or replaced when dirty?
4. Why do you think it is necessary to change 15 cu.ft. of air per minute per person in classrooms?

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose of ventilating fans.
2. Know the various types of ventilating fans.
3. Know the various sizes of ventilating fans.

Information: In our desire to control our environment, it became necessary for us to be able to move air. This is accomplished by using either intake fans, exhaust fans, or combinations of both within the same system. The State has established certain guidelines that must be followed. For example, in schools there must be definite amounts of air brought into and taken out of a classroom for each person in that room. The people who design school buildings must take this into consideration. The ventilating system must be capable of moving enough air.

You may have seen large hoods over the stoves in restaurants. They have large exhaust fans installed in these hoods to remove the heat and the odor of cooking. In industry exhaust hoods are installed to remove offensive and poisonous fumes.

The intake fan is one which brings fresh air in from the outside. The building would have some exhaust vents to remove the stale air.

The exhaust fan is one that suctions air from the building. Fresh air will enter to take the place of the air that has been removed.

Some systems have both intake and exhaust fans.

The main types of fans are:

A. The propeller type – you must be familiar with this fan. It is found around the home as an exhaust or circulating fan. It uses a screw action of a disc-like blade to move air in a straight flow.

B. Centrifugal fan – used to move large volumes of air or gas at a higher pressure than the propeller type. Air enters at the center of the wheel and due to centrifugal force is forced to the outside edge of the wheel where it increases the pressure.

The propeller or centrifugal fan can be direct or belt driven; it comes in a variety of sizes. The propeller type is for low pressure and the centrifugal is for high pressure.

Reference: Manufacturers' data sheets and catalogs.

Procedure: After having studied the information and listed reference, do the following assignment and be prepared to discuss it in class.

Assignment:

1. *Can you think of uses of fans other than those listed?*
2. Why is it important to be able to handle and control the movement of air?
3. Why do you think it necessary for the State to establish guidelines?
4. What are the two general types of fans in use today?
5. Describe each type of fan.
6. What types of drives do fans have?
7. What size fans are available today?

Objectives: *Upon completion of this lesson, the student will:*

1., Know the purpose of duct work.

2. Understand duct work design.

Information: The definition of the word "duct" is a tube, pipe, or channel for carrying liquid, air, wires, etc. We intend to discuss ducts in relation to a ventilating system.

Air-duct design is a compromise between friction loss on one hand and excessive duct size on the other. The sizes should be selected to give reasonably low friction losses without being so large as to be awkward. The space required for duct work is often a serious matter architecturally. A good air distribution system is one that permits quick, satisfactory balancing and provides the best possible comfort condition in a building.

When the duct distribution system is designed, consideration must be given to the type of foundation, number of stories, area of the house, total heat losses, location of walls, attic space available, and the location of rooms.

Most warm air ducts are installed without insulation. Because of heat gain and condensation, cooling ducts must be insulated. Ducts are also insulated to control the noise level in certain areas.

The distribution and introduction of air to the room plays a very important part in the system. One method for introducing air is to use either a *grille* which is a barred or ornamented face for an inlet or an outlet. You may use a register that also includes a damper for cutting off the air flow. Depending upon the design of the system, these air inlets and outlets can be located in the wall or ceiling. To properly do the job, the air must be circulated in the room without creating drafts. You need a reasonably uniform distribution to produce a uniform temperature and avoid the accumulation of odors.

The exhaust system and the location of exhaust grilles in the rooms are important. Corridors, the space between false ceilings, and the concrete floor can be used to advantage. Exhaust grilles must be arranged that no one will receive any uncomfortable draft. Exhaust grilles are sometimes designed with a fine-mesh screen to prevent combustible rubbish in the ducts.

Air ducts are built of galvanized stock. The sections are joined together by a lock joint. Many of today's smaller systems in one-family homes are built around fiberglass ducts.

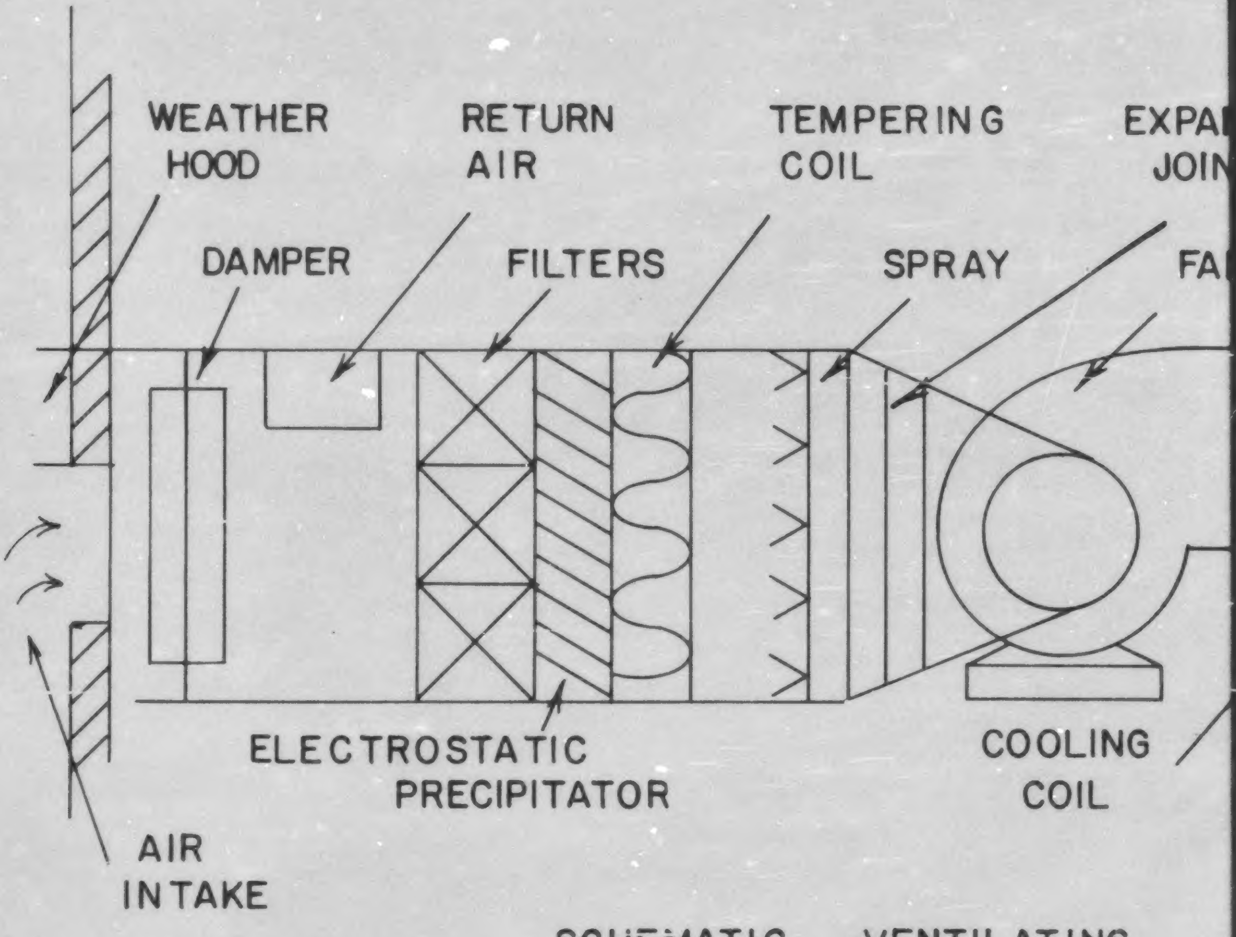
References:

1. *Heating and Air Conditioning*
2. Manufacturers' data sheets and catalogs

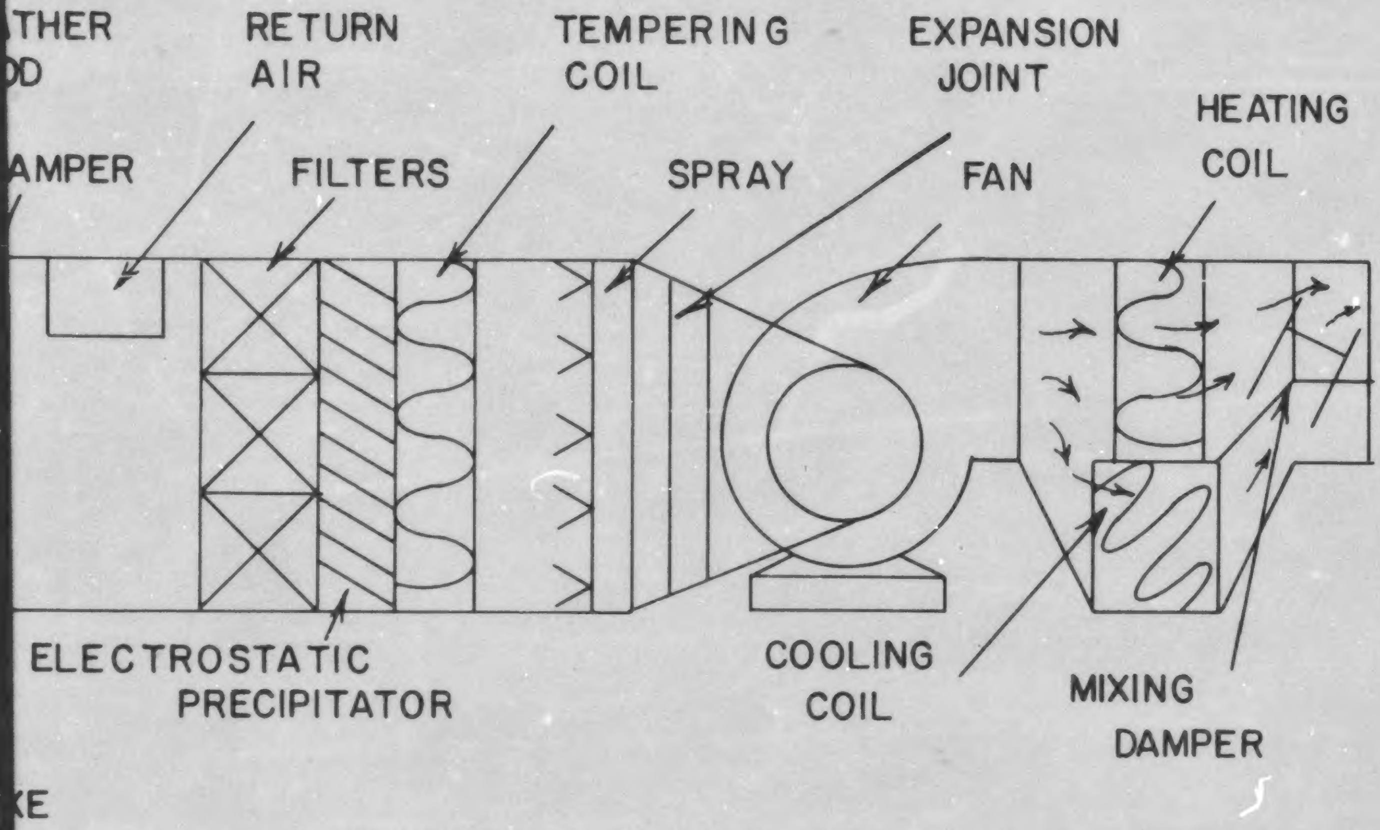
Procedure: Read the information and listed references; then do the following assignment and be prepared to discuss it in class.

Assignment:

1. What part does friction loss play in designing an air duct?
2. What is the purpose of a duct in a ventilating system?
3. Why are some ducts insulated?
4. Does it matter how the air is introduced into the room? Explain.


WEATHER HOOD
RETURN AIR
TEMPERING COIL
EXPA
JOIN
DAMPER
FILTERS
SPRAY
FA
ELECTROSTATIC PRECIPITATOR
COOLING COIL
AIR INTAKE

SCHEMATIC VENTILATING SYSTEM


ATHER
OD
AMPER
RETURN AIR
FILTERS
TEMPERING COIL
SPRAY
EXPANSION JOINT
FAN
HEATING COIL
ELECTROSTATIC PRECIPITATOR
COOLING COIL
MIXING DAMPER
KE

SCHEMATIC VENTILATING SYSTEM

Fig. XIII-C-1-1

Air Filters — Assignment XIII-D-1

Objective: Upon completion of this lesson, the student will know the purpose, location, and types of filters used in ventilating systems.

Information: Air filters are located in the duct of ventilating systems to remove lint, large dust particles, and pollen from the air.

Filters can be the replaceable type or the type that can be cleaned and reused again. The cleaning or replacement of these filters depends upon the flow of air through the filter.

Most small air conditioning and heating units use the throw away type of filter. The casing is heavy cardboard or fiber. Air passes through the filter leaving the foreign particles behind on the filter material.

Some filters are dipped into oil to coat the surfaces of the filter material. The oil traps the dirt as the air passes through the filter.

The dimensions of filters are largely standardized. Air filters should fit tightly into the holder or frame. Care must be taken in the installation of filters that no air bypasses the filter. They should be inspected periodically, cleaned, and replaced when they are heavily loaded with lint and dust.

Reference: Manufacturers' data sheets and catalogs

Procedure: Study information, manufacturers' data sheets and catalogs; then do the following assignment and be prepared to discuss questions in class.

Assignment:

1. Where is the filter located in a ventilating system?
2. Describe the two types of air filters.
3. What is the purpose of air filters in a ventilating system?

Washers and Precipitators — Assignment XIII-E-1

Objective: Upon completion of this lesson, the student will know the purpose and location of washers and precipitators.

Information: The air washer is used to remove dust from the air in addition to acting as a humidifier, dehumidifier, and cooler.

The air washer is located in the ventilating duct; it consists of three elements: the spray nozzles, the scrubber plates, and the eliminator plates.

The nozzles are placed in a bank across the path of the air. The water is forced through them by a pump and is discharged in a fine conical spray or mist in the direction of the air flow. In some cases, two or three banks of nozzles are used. The air, drawn through the washer by the fan is thus brought into intimate contact with the water, and some of the dirt and soluble gases are removed.

Scrubber plates, which are designed to change the direction of the air flow, are kept wet by the spray nozzles. The dirt in the air is thrown out from the air by its inertia and by the rubbing of air over the wet surfaces.

Following the scrubber plates are the eliminator plates whose function is to remove the trapped water from the air. The lower part of the washer is a tank in which the water collects. The water is taken from the tank by a circulating pump. A float valve admits fresh water as required.

The washer does a fair job of cleaning; it can also be used for humidifying, cooling, and dehumidifying.

Another means for removing dust from the air is the use of an electronic precipitator. This method consists of importing an electrical charge to each dust particle by passing the air between electrodes and then collecting the dust on parallel plates as the air passes between them. The precipitator is fitted into the duct work and has a very high cleaning efficiency.

References:

1. Manufacturers' data sheets and catalogs
2. *Heating and Air Conditioning*

Procedure: After having studied the above information and references, do the following assignment and be prepared to discuss it in class.

Assignment:

1. What is the purpose of the air washer and precipitator?
2. Explain the location of the air washer and precipitator and tell how they operate.

Objective: Upon completion of this lesson, the student will understand what is meant by the term *air conditioning.*

Information: The term air conditioning is misused by most people. When they think of air conditioning, they think of summer and the cooling of a house or room. This is only one small part of air conditioning.

Air conditioning involves the following:

1. Control of humidity in the air.
2. Control of the air temperature. This could mean the addition of heat or the removal of heat.
3. Circulation of air, bringing in fresh air, and the removal of stale or foul air.
4. Filtering and cleaning the incoming air.

Now, it should be obvious to you that by running an air conditioner, you are not necessarily air conditioning the air.

Reference: *Principles of Air Conditioning*

Procedure: After having studied the listed reference, do the following assignment and be prepared to discuss each in class.

Assignment:

1. Explain the 3 ways a body gives off heat.
2. What is meant by relative humidity?
3. How would you define air conditioning.

Objective: Upon completion of this lesson, the student will understand the application of domestic, commercial and industrial refrigeration.

Information: The field of refrigeration is broken up into 6 broad categories:

a. Domestic
b. Commercial
c. Industrial
d. Marine
e. Domestic air conditioning
f. Industrial air conditioning

We will only discuss the first 3 categories since air conditioning has been discussed in other assignments, and marine refrigeration could easily fall in the category of industrial refrigeration.

Domestic Refrigeration

Deals with the domestic refrigerators and freezers used in the home. This field is important because there are so many units in operation.

Commercial Refrigeration

May be broken up into (3) main groups.

1. Display cases
2. Reach-in refrigerators
3. Walk-in coolers

They are used by markets, hotels, retail stores, restaurant, etc.

Industrial Refrigeration

Larger in size than commercial units and often require a licensed engineer to operate them. They are found in frozen food lockers, ice plants, breweries, food packing plants, chemical plants, etc.

Regardless of which of the three categories we discuss, the refrigeration process remains the same. It involves three basic factors.

1. Exchange of heat.
2. Control of pressure
3. Liquid-gas relationship

The refrigeration process is simple. It consists of changing a liquid to a gas and then the gas back to a liquid. This is repeated over and over again. We will learn how this is done and the part each piece of equipment plays in the system.

Reference: Basic refrigeration book

Procedure: After having read the information and reference, do the following assignment and be prepared to discuss each in class.

Assignment:

1. List at least three applications of domestic, commercial, and industrial refrigeration.
2. What are the 3 basic factors that must be controlled in the refrigeration process?
3. What does the refrigeration process consist of?

Objectives: Upon completion of this lesson, the student will:

1. Know the air conditioning cycle.
2. Know the equipment found in the air conditioning cycle and the purpose it serves.

Information: In previous lessons the term air conditioning was explained. Now we will go into the basic air conditioning cycle. Figure XIV-C-1-1 will make the cycle easier to follow:

The fan (1) supplies air to the supply duct (2) which leads to the room (3) being serviced. The air enters the room through registers (4). The air is drawn from the room through return registers (5) to return ducts (6). The dust and impurities in the air pass through filters (7). The clean air is now passed over either heating coils (8) or cooling coils (9) depending on the time of the year.

It might be to our advantage at this time to explain in a little more detail the function of each piece of equipment.

1. **Fan** – Responsible for moving the air into and out of the space being serviced. The air usually is made up of both indoor and outdoor air. Proper fan selection is important in order to supply the correct amount of air without causing uncomfortable drafts.
2. **Supply Ducts** – Sheet metal ducts that carry the air from the fan to the room in question. They should be laid out in as short runs and with as few bends as possible. Sizing is also important; improper sizing could cause restricted air flow and a whistling noise which is most disturbing.
3. **Room Space** – The room or rooms to be serviced by an air conditioning system are an important part of the cycle. The rooms must be properly constructed and insulated to minimize the loss of heat or cooling effect that you are trying to achieve. Poor insulation and construction could put such a heavy load on a system that it would be very inefficient.
4. **Supply Register** – Needed to supply the air to the room in such a way as to eliminate annoying drafts. They are usually equipped with dampers that can be manually adjusted.
5. **Return Registers** – Usually located at extreme opposite wall from supply register. If supply register is located in the ceiling, the return register usually will be located on or near the floor.
6. **Return Ducts** – Air passes through return registers to return ducts. Then the air is brought back to be reprocessed for the next cycle.

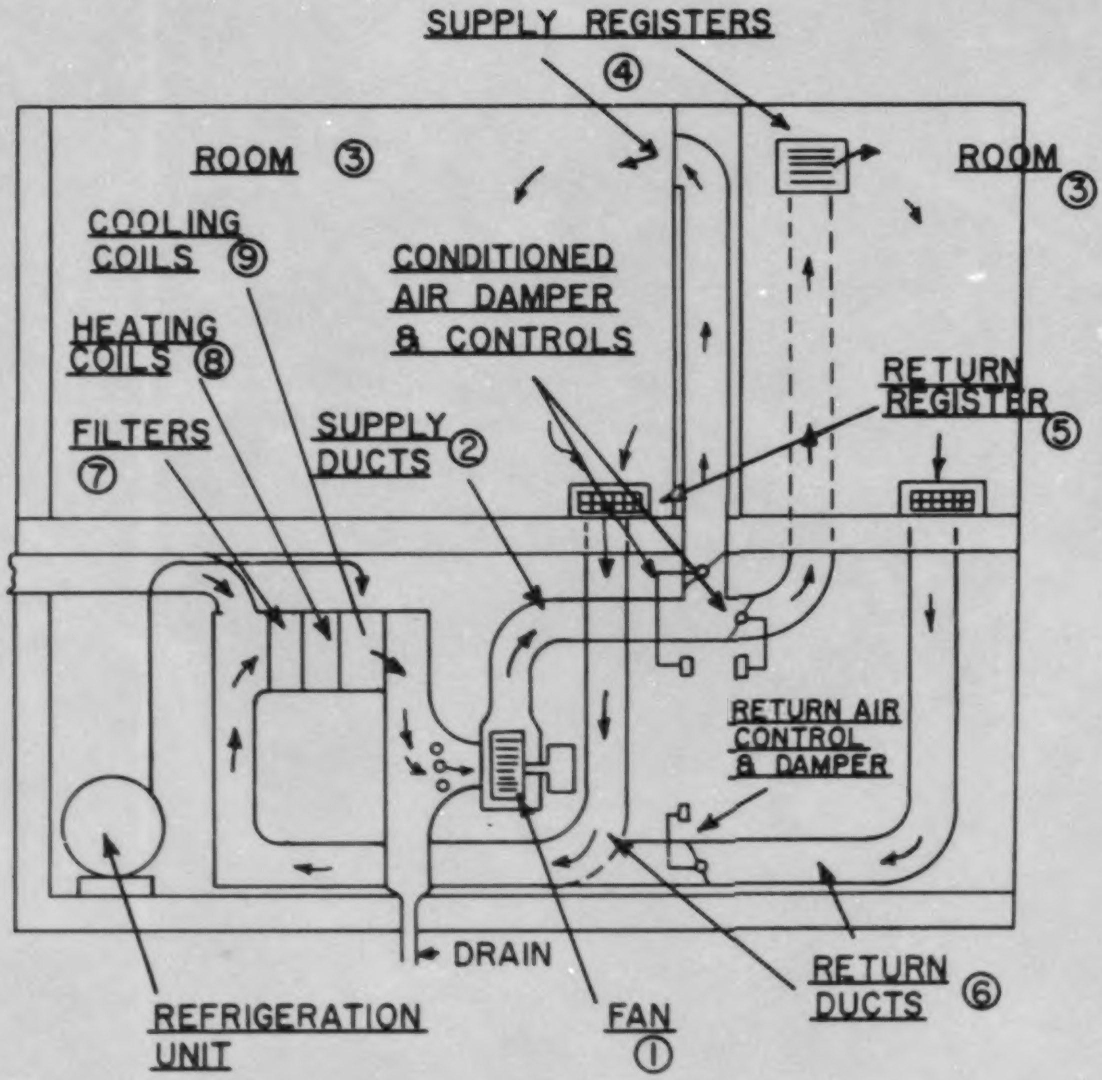
7. **Filters** – The filters are located in the return duct before the fan. They may be the reusable or throw-away type. They remove dust and dirt particles from the air. Some new systems have electrostatic precipitators that attract the dust and pollen electrically. Some filters use a water spray to trap out the dust and pollen.
8. **Heating Coils** – Located after the filter to prevent the coils from becoming loaded with dust and dirt. Only used during the heating season.
9. **Cooling Coils** – Located after the heating coils. Used during the months that require the air temperature to be lowered.

References: *Principles of Air Conditioning*, Lang
Modern Refrigeration and Air Conditioning, Althouse and Turnquist

Procedure: After having studied the listed references and information, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Why do you think outside air is necessary in the cycle?
2. What do you think would happen if the filters were not cleaned or replaced?
3. Why should the filters be located before the heating and cooling coils?
4. What would be the effects on a system running without filters?
5. What function is performed by cooling coils other than just cooling the air?


SUPPLY REGISTERS
④
ROOM ③
ROOM ③
COOLING COILS ⑨
HEATING COILS ⑧
FILTERS ⑦
SUPPLY DUCTS ②
CONDITIONED AIR DAMPER & CONTROLS
RETURN REGISTER ⑤
RETURN AIR CONTROL & DAMPER
DRAIN
REFRIGERATION UNIT
FAN ①
RETURN DUCTS ⑥

AIR CONDITIONING SYSTEM

Fig. XIV-C-1-1

Electrical Terminology — Assignment XV-A-1

Objective: Upon completion of this lesson, the student will know the meaning of such electrical terms as voltage, amperage, ohm, wattage, alternating current, and direct current.

Information: Electricity is a form of energy that can be converted from other forms of energy such as heat or mechanical energy. Electricity is a flow of electrons (negative charges) that move toward protons (positive charges.)

The *ampere* is a unit that is used to express quantity or number of electrons that are flowing per unit of time. You may think of this in the same manner as gallons per minute in a water line.

The *volt* is a unit that is used to measure the pressure differential between two points of a conductor. It is the force that is causing the electrons to move. You may also look at it as being similar to the pressure needed to have water flow in a pipe.

The *ohm* is a unit that is used to express resistance in a conductor to the flow of electrons. This is similar to the friction that occurs in pipes when water is passed through. Power is the rate of doing work.

The basic unit of electrical power is the *watt*. It can be found by multiplying the voltage times the amperage.

There are two types of electricity in use today – direct current and alternating current. *Direct current* is when the electrons flow in one direction only. *Alternating current* is when the electrons flow momentarily in one direction and then change to the other direction.

Reference: *Modern Refrigeration and Air Conditioning.*

Procedure: After having studied the above information and reference, do the following assignment and be prepared to discuss it in class.

Assignment: Give a complete definition of the following electrical terms.

a. Voltage
b. Amperage
c. Ohm
d. Wattage
e. Direct current
f. Alternating current

Ohm's Law

Assignment XV-A-2

Objective: Upon completion of this lesson, the student will understand the relationship among current, voltage and resistance in direct current circuits.

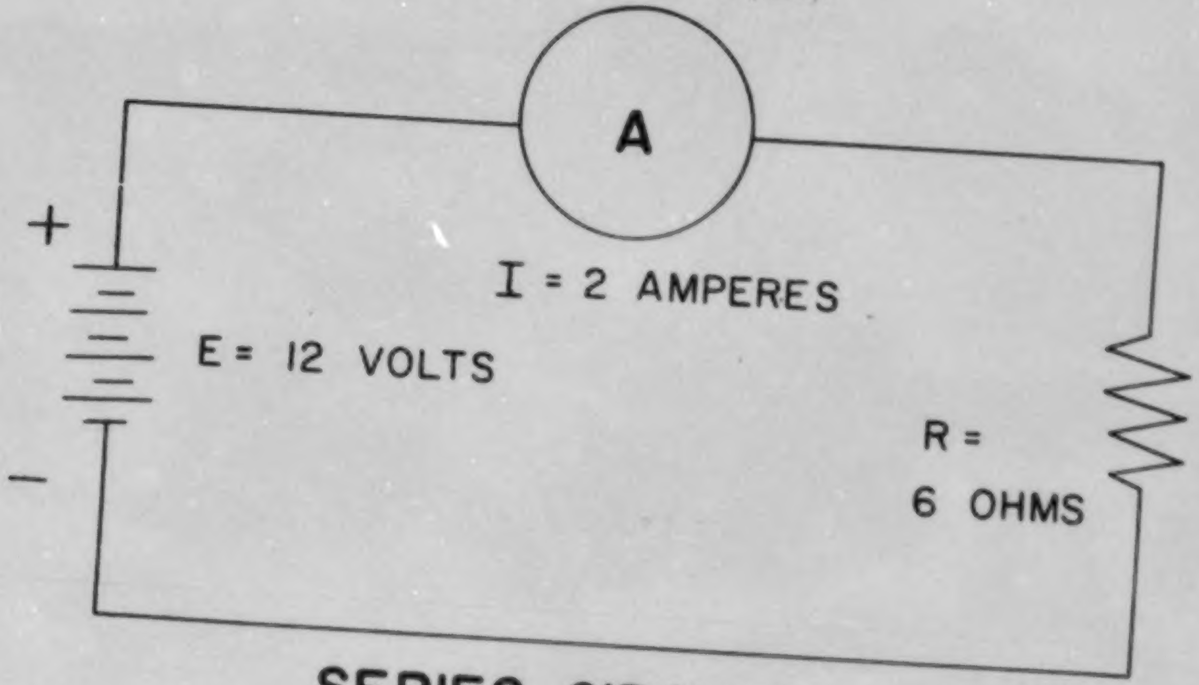
Information: The relationships of current, voltage, and resistance must be considered in every electric circuit. George Simon Ohm was the first to prove that there was a relationship between current, voltage, and resistance in a DC (direct current) circuit. Ohm's Law emerged from these experiments. The law states that the current in an electric circuit is proportional to the voltage and inversely proportional to the resistance.

It may be expressed by the following equations:

$I = \frac{E}{R}$ Current equals the voltage divided by the resistance (amps).

$R = \frac{E}{I}$ Resistance equals the voltage divided by the current (Ohms).

$E = IR$ Voltage is equal to the product of the current times the resistance (volts).



SERIES CIRCUIT

Fig. XV-A-2-1

A simple circuit diagram, Figure XV-A-2-1, is shown above. The circuit contains a 12-volt battery , an ammeter, and a resistor connected in series.

Let us now see if we can use *Ohm's Law* to solve some problems involved in our series circuit.

Example:

1. Find the current when the battery voltage is 12 volts and the resistance is 6 Ohms.

   Equation $I = \frac{E}{R}$

   Substitute $I = \frac{12}{6}$

   Solve $I = 2$ amps

2. Find the resistance when the voltage is 12 volts and the current is 2 amps.

   Equation $R = \frac{E}{I}$

   Substitute $R = \frac{12}{2}$

   Solve $R = 6$ Ohms

3. Find the voltage when the current is 2 amperes and the resistance is 6 Ohms.

   Equation $E = IR$

   Substitute $E = 2 \times 6$

   Solve $E = 12$ volts

FACTOR	UNIT	SYMBOL	MEASURE WITH	FORMULA
CURRENT	AMPERE	I	AMMETER	$I = \frac{E}{R}$
RESISTANCE	OHM	R	OHMMETER	$R = \frac{E}{I}$
VOLTAGE	VOLTS	E	VOLTMETER	$E = IR$

SUMMARY TABLE

Fig. XV-A-2-2

Procedure: After having read the information and studied the sample problems, do the following assignment.

Assignment:

1. Write the Ohm's Law equations for finding:
    a. Voltage
    b. Current
    c. Resistance
2. What current will flow through a coil having a resistance of 12 Ohms if the applied voltage is 48 volts.
3. What is the resistance of a light bulb with 1 ampere flow at 110 volts.
4. How many volts will be required to produce 1.5 amps through a coil with 6 Ohms resistance.
5. The resistance in a circuit is 100 Ohms and it is connected to a 4-volt battery. What is the amperage in the circuit?

Solving Electrical Power Problems — Assignment XV-A-3

Objective: Upon completion of this lesson, the student will know how to solve electrical power problems.

Information: Power is the rate at which work is done. In an electrical system, it is measured in watts which are based upon voltage and amperage. These terms of measurement involve force, quantity, and time. To find the power of an electric circuit in watts, you find the product of the voltage times the amperage or:

$$\text{watts} = \text{volts} \times \text{amperes}$$

$$W = E \times I$$

Because both the voltage and amperage are related to the resistance in a circuit by Ohm's Law, we can involve resistance in our power equations.

$$W = E \times I \qquad E = IR$$

Substituting IR for E we have:

$$W = IR \times I = I^2R$$

Substituting $\frac{E}{R}$ for I

$$W = E \times \frac{E}{R} = \frac{E^2}{R}$$

Power in a circuit can be expressed by the following equations:

1. $W = E \times I$
2. $W = I^2 \times R$
3. $W = \frac{E^2}{R}$

The power using the above equations will be given in watts. This may be converted to kilowatts by dividing watts by 1000.

1 KW = 1000 watts

By multiplying the number of kilowatts used in an electrical system by the number of hours it was used, you can determine the total power used.

Example: If 100 KW were used for a period of 12 hours, then the total power used would be:

KW × HR = KWHR or Kilowatt Hours

100 × 12 = 1200 KWHR

Procedure: After having studied the above information, do the following assignment.

Assignment: 1. How many watts would be used in each of the following circuits.

   a. 120 volt at 5 amps
   b. 1000 Ohm resistor at 1 amp
   c. 6-Ohm resistor at 12 volts
   d. 9 amps at 120 volts

2. What is the resistance of a 60 watt, 120 volt lamp?

3. Find the current for a 800 watt, 120 volt toaster.

4. What will it cost to run the toaster in problem 3 for 5 hours if energy costs 3 cents per KWH.

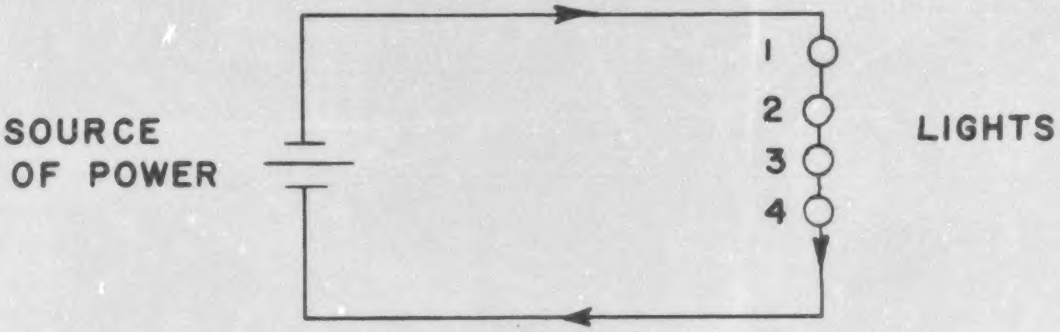
5. A 6-volt battery is charged at a 5-amp rate for 24 hours. How many KWHR of energy is put into the battery.

Objectives: Upon completion of this lesson, the student will:

1. Know how a simple series circuit is connected.
2. Know how a simple parallel circuit is connected.
3. Know how a series-parallel circuit is connected.

Information: An electrical circuit is a path over which an electrical current moves from its source to motors, heaters, lights, controls, or other electrically operated equipment. This is usually done with copper wire that is connected to all parts of the circuit.

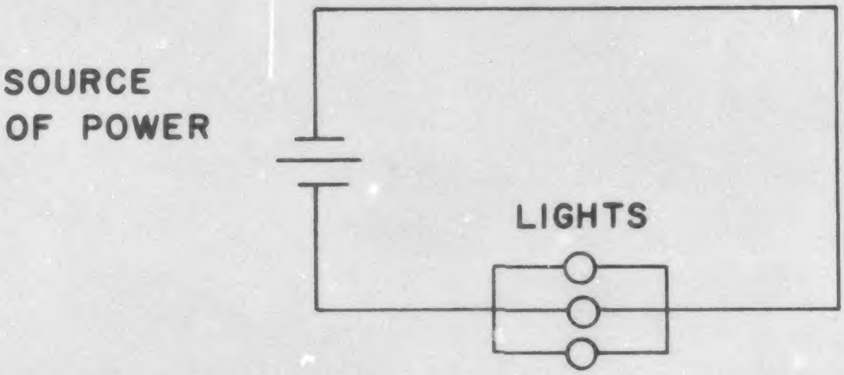
A series circuit has the resistances such as lights or controls in line with each other.



SERIES CIRCUIT

Fig. XV-B-1-1

A parallel circuit has the resistances along side of each other as in the following sketch.



PARALLEL CIRCUIT

Fig. XV-B-1-2

A series-parallel circuit combines both series and parallel circuits into one circuit.

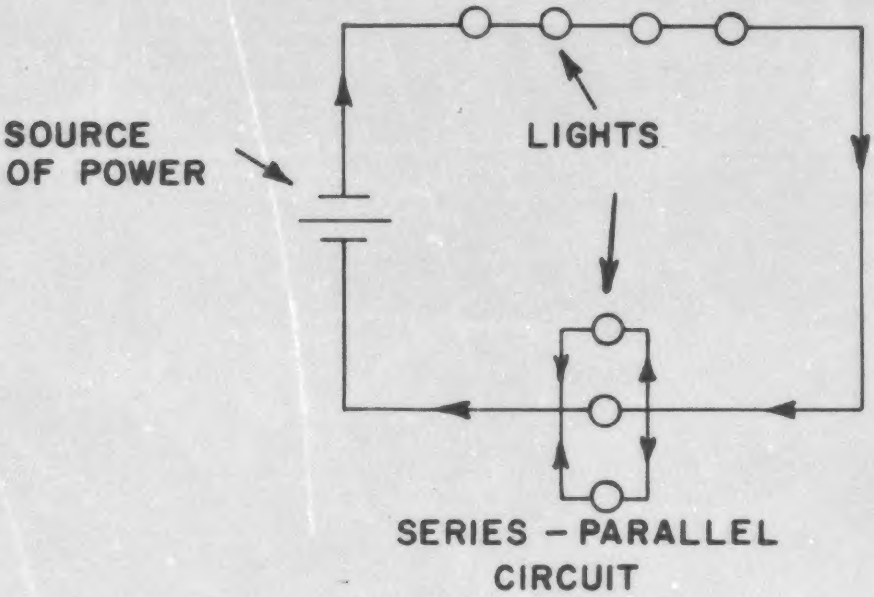


Fig. XV-B-1-3

Reference: Basic electricity text

Procedure: After reading the above information and reference, do the following assignment and be prepared to discuss it in class.

Assignment:

1. Show with a line drawing a series circuit with the following components: 3 switches, 3 lamps.
2. Show with a line drawing a parallel circuit with the following components: 3 motors, 3 heaters.
3. Show with a line drawing a series-parallel circuit with the following components: 2 motors in parallel, 2 lamps in series.

Objectives: Upon completion of this lesson, the student will:

1. Know how to find the value of the current in a series circuit.
2. Know how to find the total resistance in a series circuit.
3. Know how to find the voltage across any resistor in a series circuit.

Information: In a series circuit, there is only one path for the current to take. Each device is connected together in a continuous path.

Because there is only one path, they are said to be in series and the current moving through this circuit must be the same throughout. See figure XV-B-2-1.

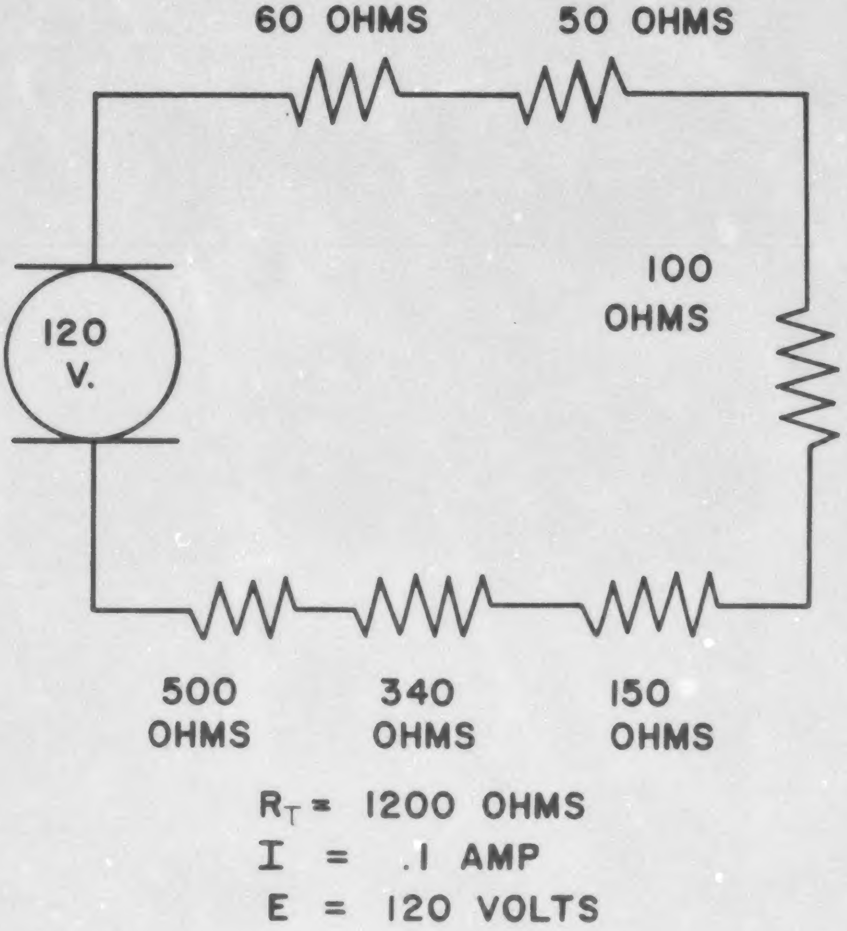

60 OHMS
50 OHMS
120 V.
100 OHMS
500 OHMS
340 OHMS
150 OHMS
R_T = 1200 OHMS
I = .1 AMP
E = 120 VOLTS

Fig. XV-B-2-1

The total resistance in a series circuit is the sum of the resistances in the circuit.

$$R_t = R_1 + R_2 + R_3 \text{ etc.}$$

The current in a series circuit is dependent upon the voltage applied to the circuit and the total resistance within the circuit.

$$I = \frac{E}{R_t} = I \text{ (amperes)} = \frac{E \text{ (voltage)}}{R_t \text{ (total resistance)}}$$

Example: 1. If six resistors are connected in series as in the Figure XV-B-2-1, what will be the total resistance in the circuit.

$$R_t = R_1 + R_2 + R_3 + R_4 + R_5 + R_6$$

$$R_t = 60 + 50 + 100 + 150 + 340 + 500$$

$$R_t = 1200 \text{ ohms}$$

To find the current in the circuit

$$I = \frac{E}{R_t}$$

$$I = \frac{120}{1200} = .1 \text{ amp.}$$

In the example above, we have applied Ohm's Law to the entire circuit, but it may also be applied to each part of the circuit.

Example 2. What is the voltage across each resistor in the circuit?

$E = IR_1$ | $E = IR_2$ | $E = IR_3$
$E = .1 \times 60$ | $E = .1 \times 50$ | $E = .1 \times 100$
$E = 6$ volts | $E = 5$ volts | $E = 10$ volts

$E = IR_4$ | $E = IR_5$ | $E = IR_6$
$E = .1 \times 150$ | $E = .1 \times 340$ | $E = .1 \times 500$
$E = 15$ volts | $E = 34$ volts | $E = 50$ volts

From this example, you may have noticed that the sum of the voltages across each resistor is equal to the applied voltage.

$$E = E_1 + E_2 + E_3 + E_4$$

$$E = 6 + 5 + 10 + 15 + 34 + 50$$

$$E = 120 \text{ volts}$$

Facts to remember:

1. The current in a series circuit is the same throughout the circuit.
2. Total resistance is the sum of the resistors in a circuit.
3. The sum of the voltage across each resistor is equal to the applied voltage.

Reference: Basic electricity text

Procedure: After having studied the above information and reference, do the following assignment.

Assignment:

1. What is the current in a series circuit with 120 volts applied voltage and the following resistors.

a.	10-ohm	50-ohm	40-ohm
b.	5-ohm	8-ohm	12-ohm
c.	12-ohm	24-ohm	48-ohm

2. Find the voltage across each resistor in Problem 1.
3. From a 120-volt source, two resistors are connected in series; one is 30 Ohms and has 15 volts across it; the resistance of the other resistor is unknown.

   Find:
   - a. current in each resistor.
   - b. resistance of unknown resistor.
4. From Figure XV-B-2-2, find:
   - a. value of R_2
   - b. voltage across R_2

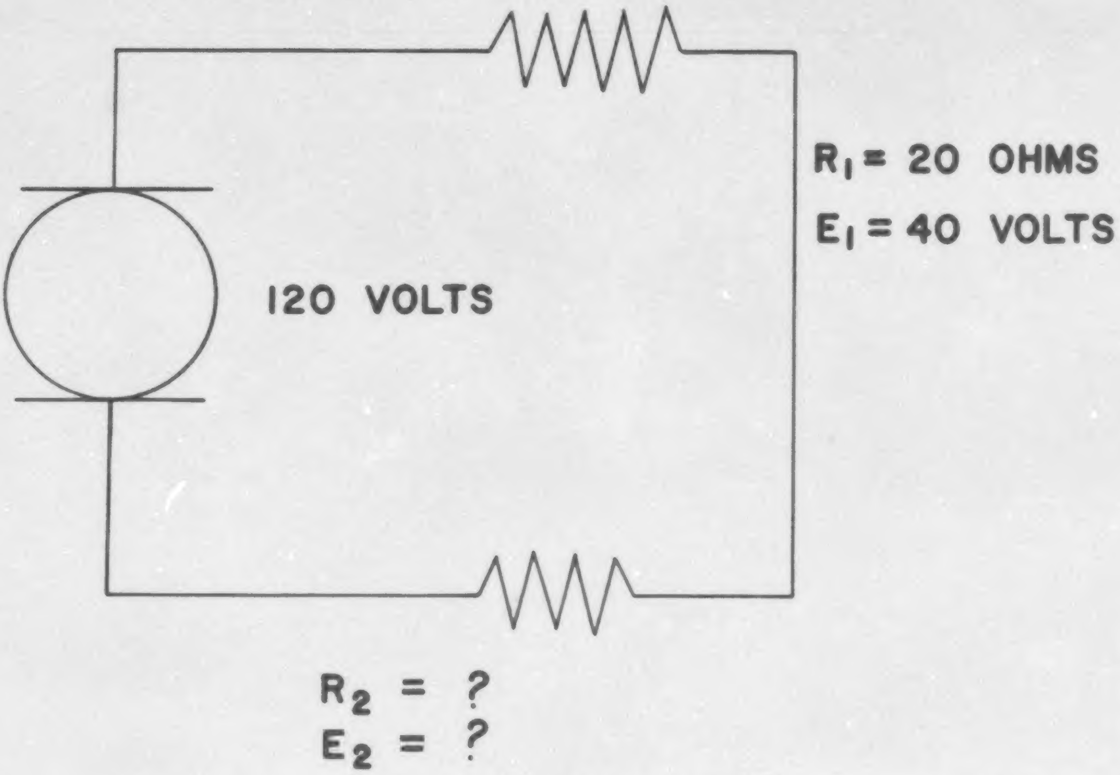


Fig. XV-B-2-2

Objective: Upon completion of this lesson, the student will know how to apply Ohm's Law to parallel circuits.

Information: In a parallel circuit, each path (or branch) is connected directly across the voltage source as shown in figure XV-B-2-1. The voltage is the same across each branch.

The current through each branch is independent of the others and depends only on the resistance of that particular branch and that voltage. The current through each branch may thus be computed separately. Using the values in the sketch, the current will be:

$$I_1 = \frac{E}{R_1} = \frac{30}{5} = 6 \text{ amps}$$

$$I_2 = \frac{E}{R_2} = \frac{30}{10} = 3 \text{ amps}$$

$$I_3 = \frac{E}{R_3} = \frac{30}{30} = 1 \text{ amps}$$

The total current of the parallel circuit is equal to the sum of the currents through the individual branches.

$$I_t = I_1 + I_2 + I_3$$

$$I_t = 6 + 3 + 1$$

$$I_t = 10 \text{ amps}$$

To find the total resistance of a parallel circuit, you can use the following equation:

$$\frac{1}{R_t} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{ etc.}$$

Using the values from the sketch,

$$\frac{1}{R_t} = \frac{1}{5} + \frac{1}{10} + \frac{1}{30}$$

$$\frac{1}{R_t} = \frac{10}{30} = \frac{1}{3}$$

$$R_t = 3 \text{ ohms}$$

As in the series circuit, the total power used is equal to the sum of the power consumed in the individual resistors.

$$W_1 = EI_1 = 30 \times 6 = 180 \text{ watts}$$

$$W_2 = EI_2 = 30 \times 3 = 90 \text{ watts}$$

$$W_3 = EI_3 = 30 \times 1 = 30 \text{ watts}$$

$$\text{Total power} = 180 + 90 + 30 = 300 \text{ watts or}$$

$$W_t = EI_t = 30 \times 10 = 300 \text{ watts}$$

Reference: Basic electricity text

Procedure: After having studied the above information and reference, complete the following assignment and be prepared to discuss it in the class.

Assignment: The parallel circuit Figure XV-B-3-2 has 2 branches, A and B.

Branch A consists of 3 lamps in parallel with the following ratings:

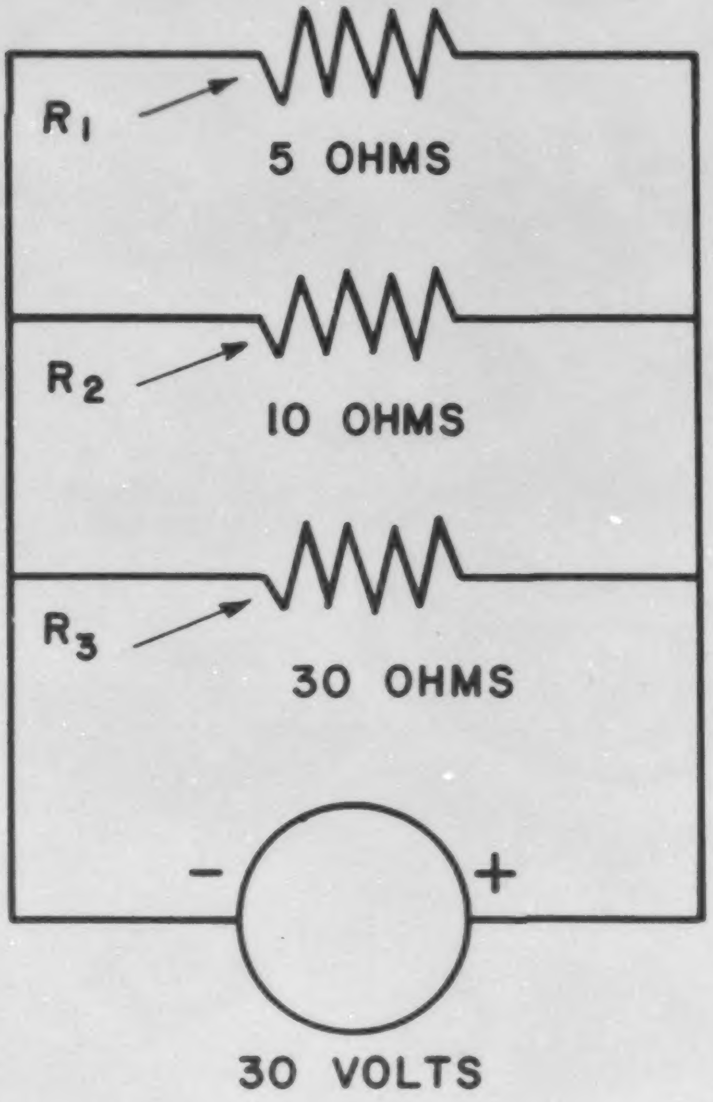
L_1 = 50 watts L_2 = 24 watts L_3 = 75 watts

Branch B also has 3 lamps in parallel with ratings of:

L_4 = 150 watts L_5 = 200 watts L_6 = 250 watts

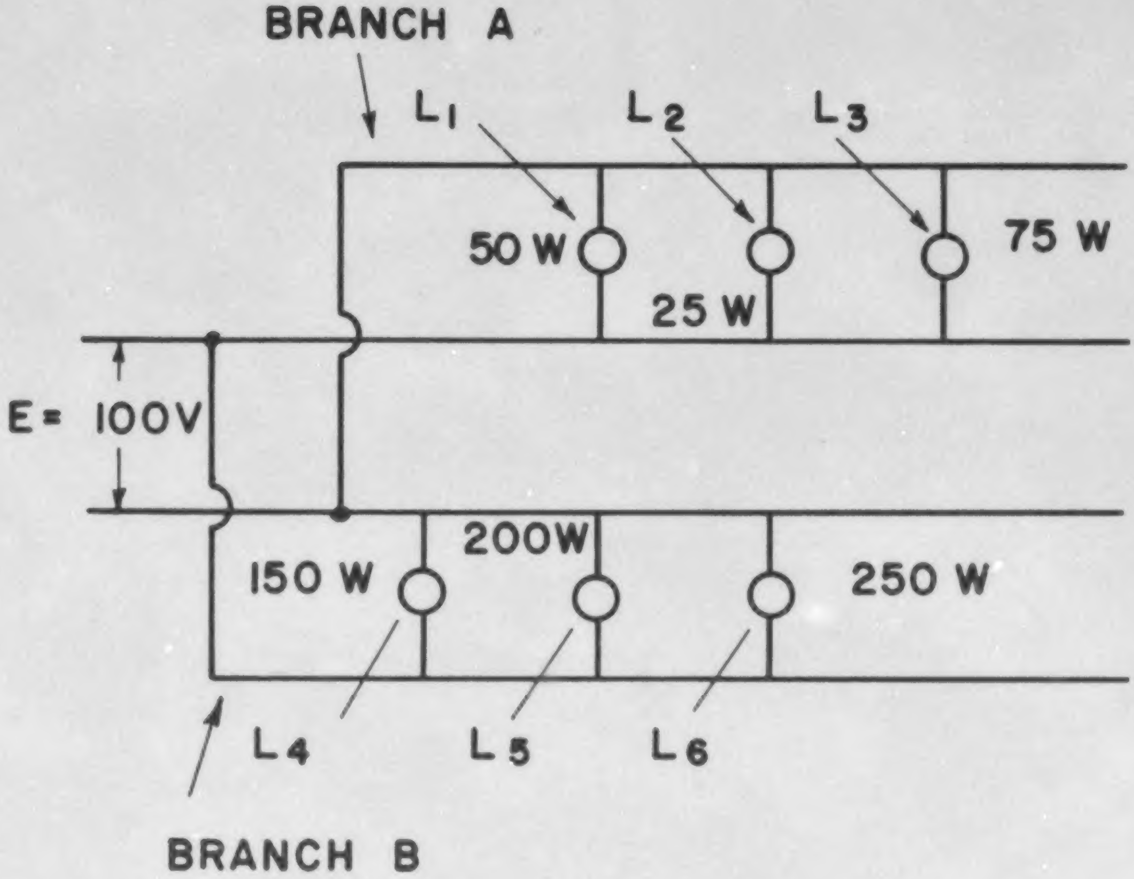
The voltage across the circuit is 100 volts.

1. Find the current in each lamp.
2. Find the resistance of each lamp.
3. Find the current in branch A.
4. Find the current in branch B.
5. Find the total circuit current.
6. Find the total circuit resistance.
7. Find the total power supplied to the circuit.


R1
5 OHMS
R2
10 OHMS
R3
30 OHMS
−
+
30 VOLTS

SIMPLE PARALLEL CIRCUIT

Fig. XV-B-3-1


BRANCH A
L1
L2
L3
50 W
25 W
75 W
E= 100V
200W
150 W
250 W
L4
L5
L6
BRANCH B

PARALLEL CIRCUIT

Fig. XV-B-3-2

Series-Parallel Circuits

Objectives: Upon completion of this lesson, the student will be able to:

1. Simplify series-parallel circuit problems.
2. Solve series-parallel circuit problems.

Information: Series-parallel circuits are made up of combinations of series and parallel circuits. They can be quite complicated, but they may be solved by applying the same basic rules that we used in solving problems in series and parallel circuits. The series-parallel circuit has to be simplified by separating and solving the series and parallel problems within it.

The drawings attached represent two series-parallel circuits.

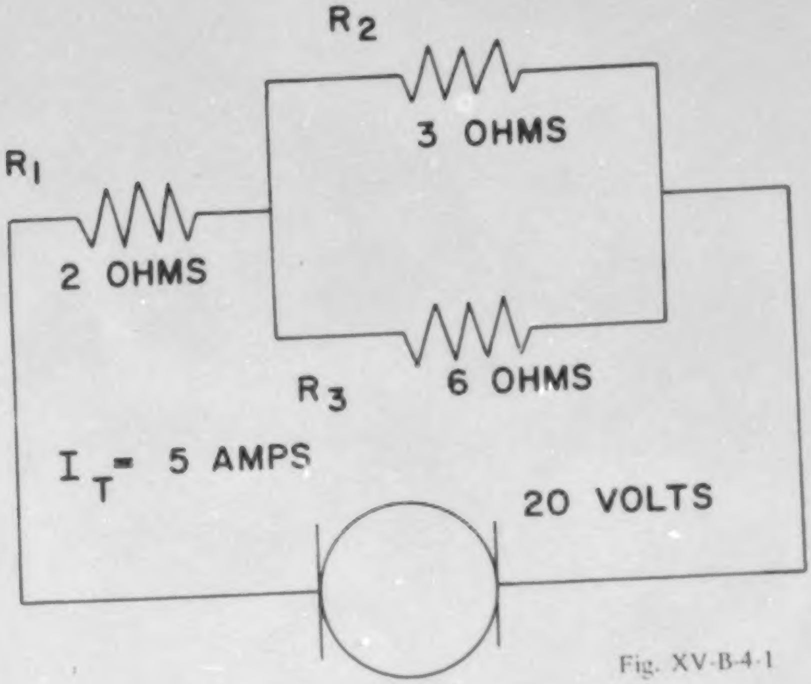


Fig. XV-B-4-1

In drawing XV-B-4-1, R_2 and R_3 are in parallel; therefore the total resistance of R_2 and R_3 will be:

$$\frac{1}{R_{2,3}} = \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R_{2,3}} = \frac{1}{3} + \frac{1}{6}$$

$$\frac{1}{R_{2,3}} = \frac{1}{2} \text{ Ohm}$$

$$R_{2,3} = 2 \text{ Ohms}$$

$R_{2,3}$ and R_1 are in series, so the total resistance of the circuit will be:

$$R_t = R_{2,3} + R_1$$

$$R_t = 2 + 2$$

$$R_t = 4 \text{ Ohms}$$

Using Ohm's Law, you can find the total current in the circuit.

$$I_t = \frac{E}{R_t}$$

$$I_t = \frac{20}{4}$$

$$I_t = 5 \text{ amps}$$

The voltage across each resistor is:

$$E_{R_1} = I_t R_1$$

$$E_{R_1} = 5 \times 2$$

$$E_{R_1} = 10 \text{ volts}$$

$$E_{2,3} = I_t R_{2,3}$$

$$E_{2,3} = 5 \times 2$$

$$E_{2,3} = 10 \text{ volts}$$

The voltage across R_2 and R_3 is 10 volts; then current will be:

$$I_2 = \frac{E}{R_2}$$

$$I_2 = \frac{10}{3}$$

$$I_2 = 3\text{-}1/3 = 3.33 \text{ amps.}$$

$$I_3 = \frac{E}{R_3}$$

$$I_3 = \frac{10}{6}$$

$$I_3 = 1\text{-}2/3 = 1.66 \text{ amps.}$$

In drawing XV-B-4-2, R_2 and R_3 are in series; therefore, the total resistance is:

$$R_{2,3} = R_2 + R_3$$

$$R_{2,3} = 2 + 10$$

$$R_{2,3} = 12 \text{ Ohms}$$

The total resistance in the circuit is found by combining $R_{2,3}$ in parallel with R_1.

$$\frac{1}{R_t} = \frac{1}{R_{2,3}} + \frac{1}{R_1}$$

$$\frac{1}{R_t} = \frac{1}{12} + \frac{1}{6}$$

$$\frac{1}{R_t} = \frac{1}{4}$$

$$R_t = 4 \text{ Ohms}$$

The total current will equal:

$$I_t = \frac{E}{R_t}$$

$$I_t = \frac{20}{4}$$

$$I_t = 5 \text{ amps}$$

The current through R_1 will be:

$$I_1 = \frac{E}{R_1}$$

$$I_1 = \frac{20}{6}$$

$$I_1 = 3\text{-}1/3 = 3.33 \text{ amps}$$

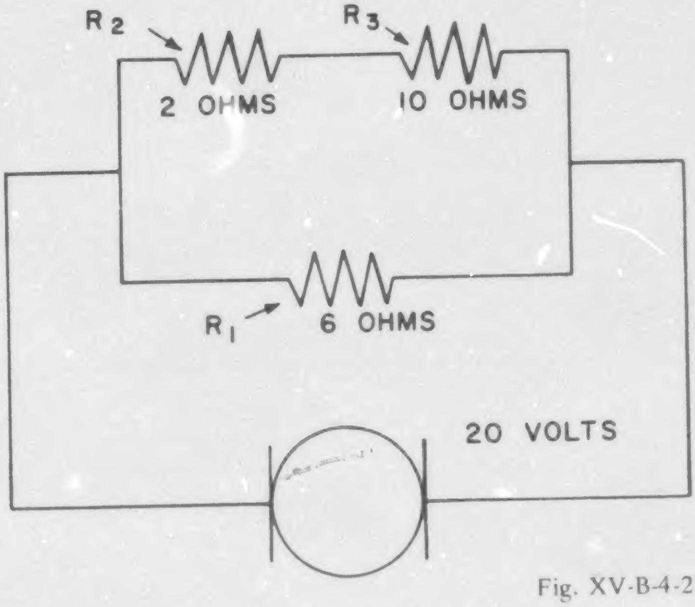


Fig. XV-B-4-2

The current through R_2 and R_3 is:

$$I_{2,3} = \frac{E}{R_{2,3}}$$

$$I_{2,3} = \frac{20}{12}$$

$$I_{2,3} = 1\text{-}2/3 = 1.66 \text{ amps}$$

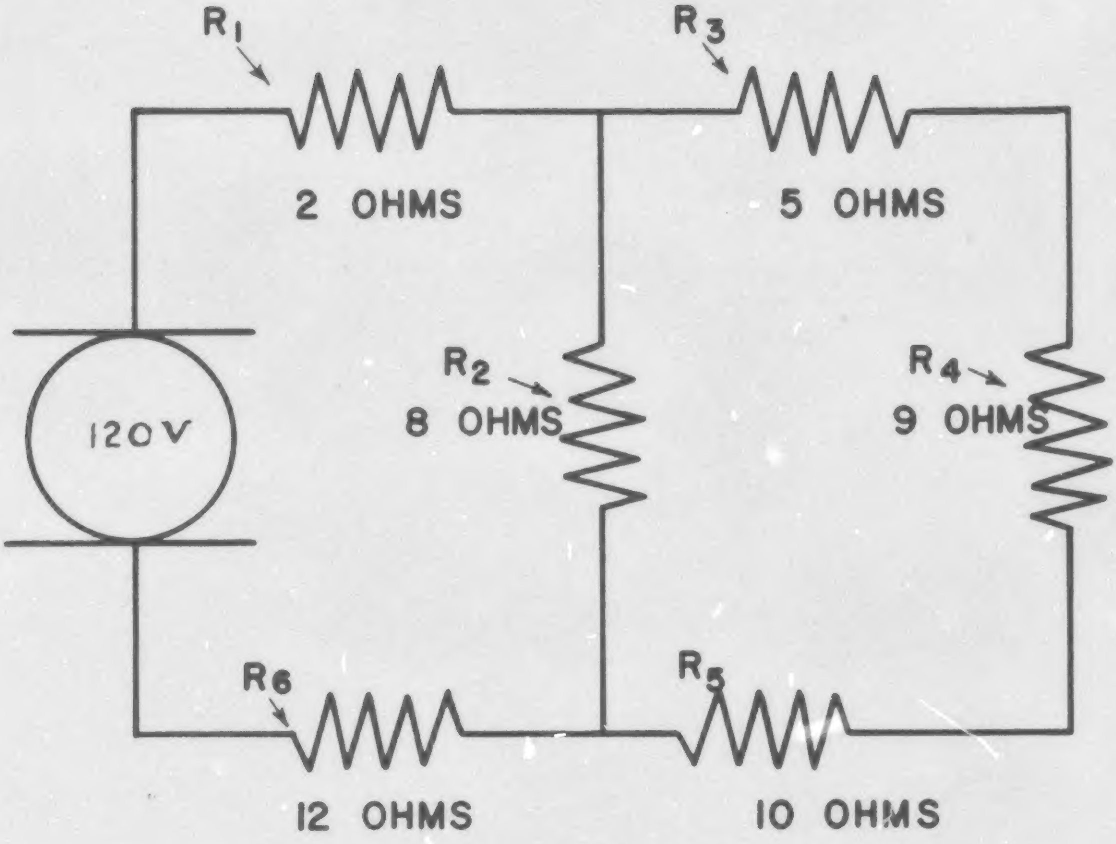
By applying the series and parallel circuit formulas, we can solve problems in series-parallel circuitry.

Reference: Basic electricity text

Procedure: After having studied the above information and reference, complete the following assignment.

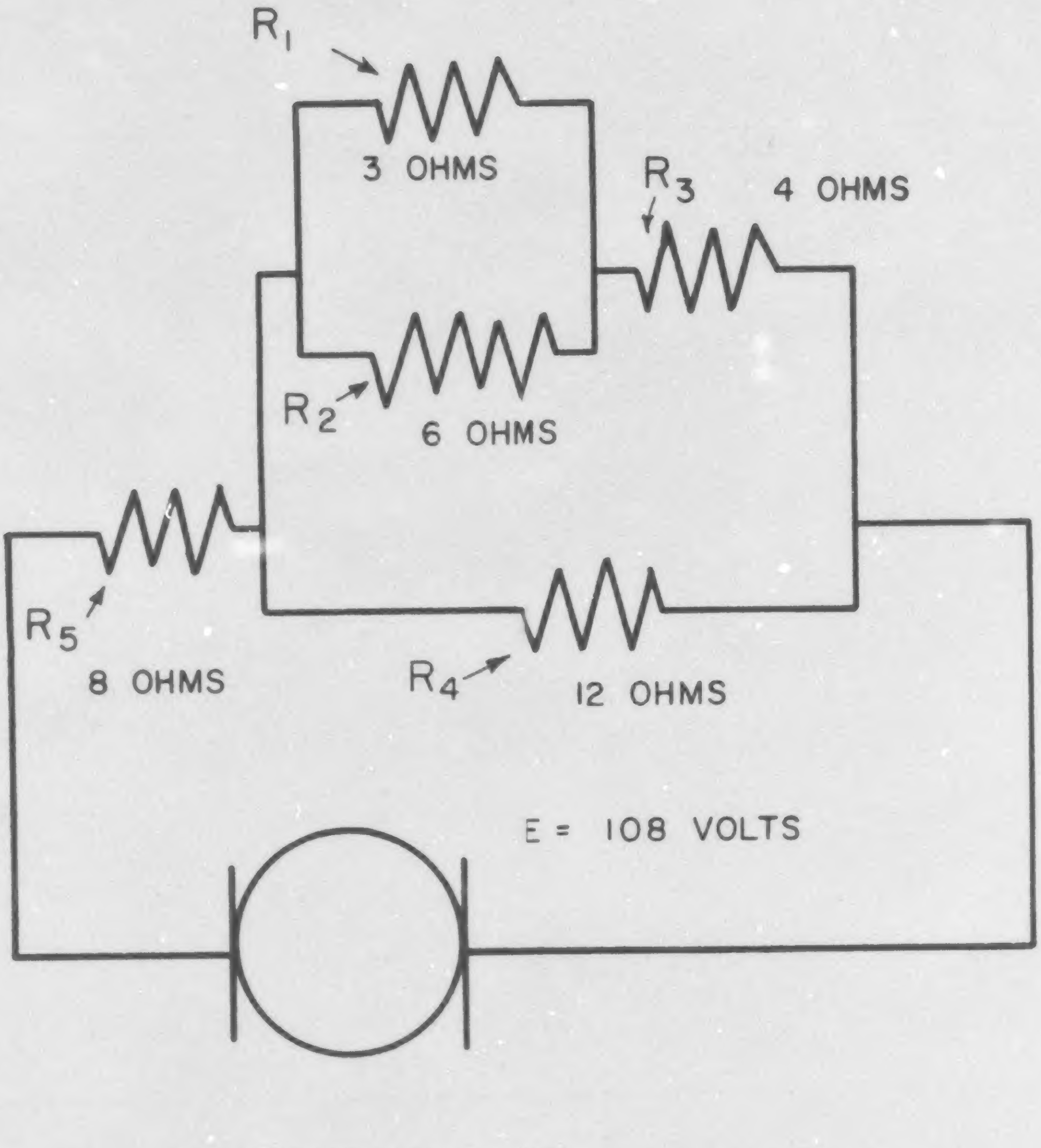
Assignment:

1. In circuit A, Figure XV-B-4-3, solve for:
    - a. total resistance
    - b. voltage across each resistor
    - c. total current
    - d. current through each resistor
    - e. power of the circuit
2. In circuit B, Figure XV-B-4-4, solve for:
    - a. total resistance
    - b. voltage across each resistor
    - c. total current
    - d. current through each resistor
    - e. power in the circuit


R_1
2 OHMS
R_3
5 OHMS
120V
R_2
8 OHMS
R_4
9 OHMS
R_6
12 OHMS
R_5
10 OHMS

CIRCUIT A

Fig. XV-B-4-3


R_1
3 OHMS
R_3
4 OHMS
R_2
6 OHMS
R_5
8 OHMS
R_4
12 OHMS
E = 108 VOLTS

CIRCUIT B

Fig. XV-B-4-4

Magnetism **Assignment XV-C-1**

Objectives: Upon completion of this lesson, the student will know what magnetism is.

Information: The two fundamental and invisible forces which are responsible for the wonders of electronics are electric force and magnetic force. These are the forces which make possible the operation of electric motors, generators, lights, doorbells, measuring instruments, and other electrical apparatus.

It is a magnetic force which attracts small bits of iron and steel to the end of the ordinary horseshoe magnet. This same magnetic force swings a compass needle toward the north.

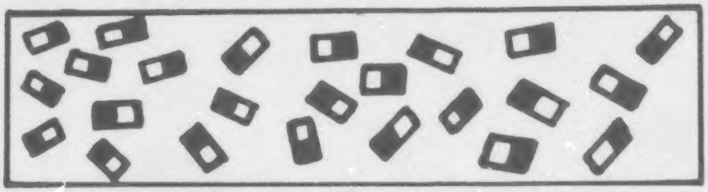
The ancient Greeks knew that certain stones had the property of attracting bits of iron which they called magnetite. Today, it is known that magnetite is an iron ore possessing magnetic qualities.

A common theory of magnetism is that a piece of iron or steel consists of millions of tiny elementary magnets which are so small that they cannot be seen with a microscope. They may consist of atoms or molecules so aligned as to form iron or steel crystals. Before a piece of iron or steel has been magnetized, these tiny magnets may be thought of as being jumbled at random with no definite order. If the north pole of an inducing magnet is drawn over the bar, it attracts the south poles of the tiny magnets and turns them so that they will align themselves in a given direction. This alignment of molecular magnets will give the bar a definite north pole at one end and a south pole at the other end.

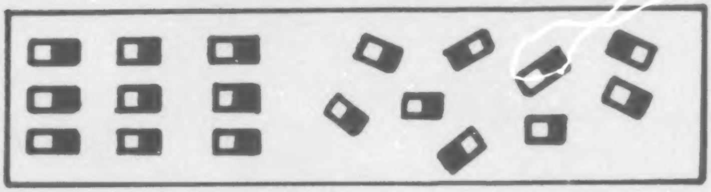
The fundamental Law of Magnetic Forces is: *Like magnetic poles repel each other; unlike magnetic poles attract each other.*

The amount of magnetic force existing in the space surrounding a magnet can be estimated roughly by measuring its lifting power. This lifting power will vary because of the kinds of materials to be lifted. A more accurate method for measuring the strength of a magnet is by measuring the force of attraction or repulsion that the magnet has on another magnet of known strength.

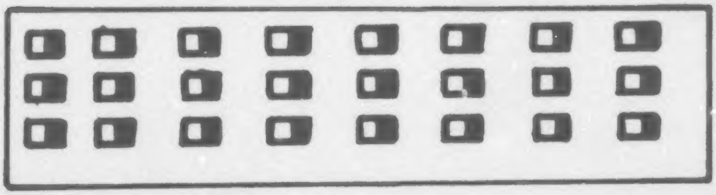
The space which surrounds a magnet is called the external magnetic field. This field may be defined as a region wherein magnetic forces act.



UNMAGNETIZED



PARTIALLY MAGNETIZED



MAGNETIZED

Fig. XV-C-1-1

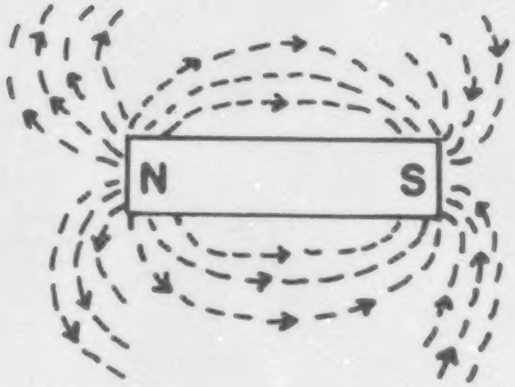
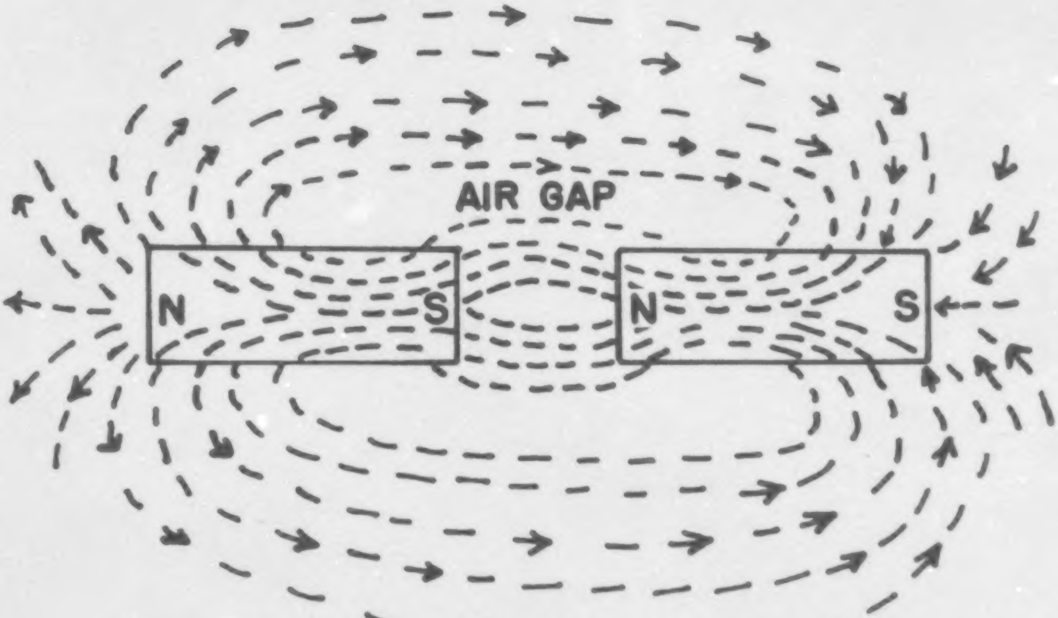


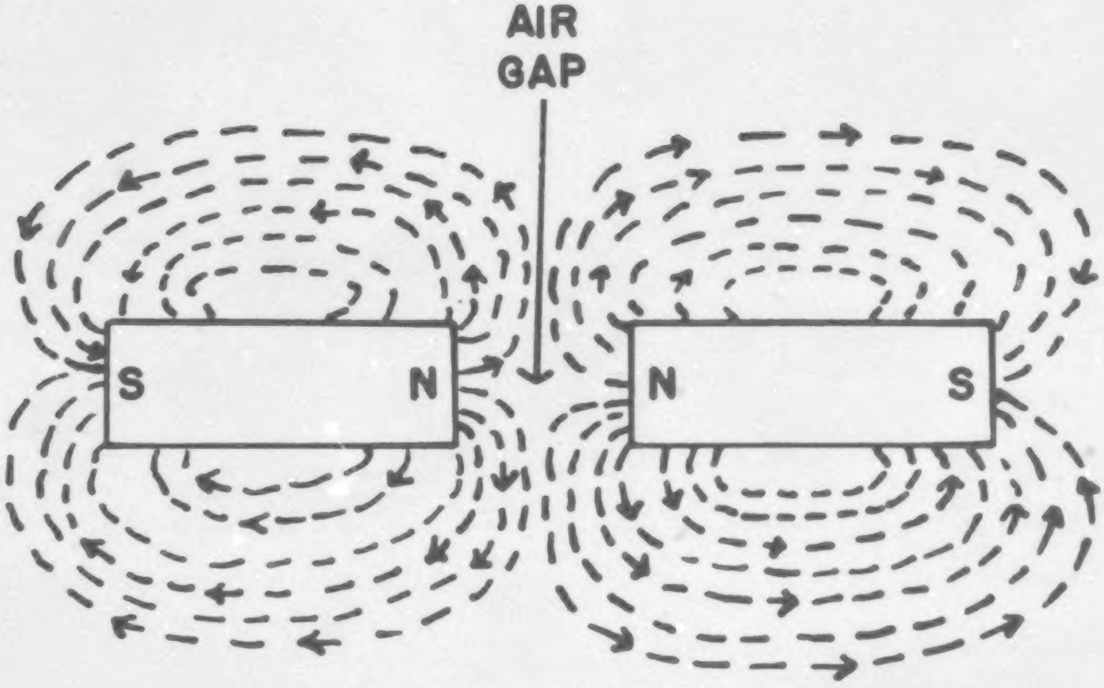
Fig. XV-C-1-2

LINES OF FORCE


AIR GAP
N
S
N
S

UNLIKE POLES ATTRACT

Fig. XV-C-1-3



LIKE POLES REPEL

Fig. XV-C-1-4

References:
1. Basic electricity text
2. *Electrical Fundamentals*
3. *Refrigeration, Air Conditioning, and Cold Storage*

Procedure: After having studied the above references and information, do the following assignment.

Assignment:
1. Explain what a natural magnet is.
2. What is a magnetic pole?
3. What are the fundamental Laws of Magnetic Forces?
4. What two forces govern the force of attraction or repulsion between two magnetic poles?
5. What is a magnetic field?

Motors (Function and Types) — Assignment XV-D-1

Objectives: Upon completion of this lesson, the student will:

1. Know the function of a motor.
2. Know the different types of motors.

Information: The past 50 years have seen the electric motor take its place as the most widely used machine in industry. The electric motor industry has advanced far since the days of the first units. Many of today's construction features, protection enclosures housing horsepowers ten times formerly contained in a given frame, and the thin-skinned highly efficient insulation was far beyond the horizon of early designers. The motor converts electrical energy into shaft horsepower and is used to drive a multitude of machinery. Because of the convenience of operation and low operating costs, the electrical motor has replaced the steam engine and steam turbine as the most popular prime mover of such equipment as pumps, compressors, and fans.

Motors may be divided into different categories such as fractional horsepower and motors of 1 hp and over. Motors are either "open" or totally enclosed. They may be broken down into more descriptive categories such as drip-proof, splash-proof, weather protected, pipe ventilated, fan cooled, and explosion-proof. Motors may be a.c. or d.c. and single phase or polyphase.

Important factors to consider when selecting a motor are:

1. Temperature, dust, moisture, or explosive materials at the point of installation.
2. Starting torque requirements.
3. Starting current limitations.

[illegible] Single or multispeed operation.

5. Continuous or intermittent operation.
6. Efficiency and power factor.

Motors are designed to operate at specific temperatures above the surrounding air temperatures under full load conditions without overheating. Continuous operation of a motor under overload conditions will cause excessive winding temperatures and shorten the life of the insulation.

Single-phase motors commonly used in the refrigerating industry are of the following types: (1) split-phase, (2) capacitor start, (3) capacitor start and run, (4) permanent capacitor, (5) shaded pole.

All these motors are induction motors and all employ a squirrel cage rotor. The principal factor which distinguishes one type from another is the particular method used to produce a starting torque.

Three-phase induction motors are of two general types: (1) squirrel cage and (2) wound rotor. The squirrel cage induction motor is by far the most common type of these phase motors.

Synchronous motors are used in large installations, where constant speed and high efficiency are desired.

References:

1. *Practical Power Service Library*
2. *Principles of Refrigeration*
3. *Modern Refrigeration and Air Conditioning*
4. *Refrigeration, Air Conditioning, and Cold Storage*

Procedure: After having studied the information and listed references, answer the following questions and be prepared to discuss them in class.

Assignment:

1. Explain why motors are designed differently.
2. What are some of the factors that determine the type of motor which is used?
3. Name some parts of an electric motor.
4. Why did electric motors replace steam engines and turbines?
5. Name the different types of electric motors.

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with single and polyphase motors.
2. Be familiar with motor overload protection.

Information: Single- and three-phase circuits are generally used for refrigeration purposes. Single-phase circuits are made up of two wires while three-phase requires a three wire and sometimes a four-wire circuit.

For every cycle, there is one phase of current in a single-phase circuit. A polyphase circuit has two or three separate supplies of single-phase current arranged so that the peaks of voltage follow each other in a regular repeating action. Each phase is 1/180 of a second or 1/3 of a cycle apart in a 3-phase, 60-cycle current circuit.

The single-phase induction motor is similar to the polyphase squirrel-cage induction motor in its construction. Only one winding is employed, which does not cover the entire internal periphery of the stator as do the two or three windings of polyphase motors. When a single-phase stator winding is energized, current flow is simultaneous in all the stator poles. No rotating stator field is produced. Furthermore, the current induced in the squirrel-cage motor winding is such that the magnetic field set up in the rotor is exactly in line with the magnetic field of the stator. Therefore, there is no tendency for the rotor to rotate. However, if the rotor starts to rotate by some means, the current induced in the rotor winding will lag slightly behind the current in the stator winding. This causes the rotor field to lag the stator field and produce a torque that keeps the rotor turning. Hence, once the rotor of a single-phase motor is started, a rotating field is produced and the motor operates in a manner similar to that of the 3-phase squirrel-cage motor.

In order to produce a starting torque in a single-phase motor, several alternatives are used. A split-phase motor has a starting winding with a higher resistance than the running windings. This causes the current flow in the starting winding to lag 30° behind or out of phase with the running windings. This produces a starting torque and causes the motor to rotate. When the rotor is 70% up to full speed, a centrifugal switch opens up in the starting windings. These motors do have a low starting torque and are available in sizes ranging from 1/20 to 1/3 hp, 115 V or 230 V, and are used to drive small fans, blowers, and pumps.

Capacitor-start motors are identical to the split-phase motor except for a capacitor placed in series with the starting windings. The starting windings are usually wound with larger wires than in the split-phase. The capacitor causes the current to lead the voltage and whereas the current lags, the voltage is in the running winding. This can cause a phase displacement between the two windings up to 90°. It gives it a high starting torque making it ideal to drive small compressors that must start under full-load conditions. The starting winding is taken out of the circuit when the rotor reaches 70% of maximum speed.

Other single-phase motors are capacity start and run, permanent capacitor motors, and shaded-pole motors.

Three-phase induction motors are of two general types – the squirrel cage and the wound rotor. These motors have three separate stator windings, one for each phase, which are distributed 120° apart around the stator producing a rotating magnetic field. The magnetic poles of the rotor field are attracted by and tend to follow the poles of the rotating stator field. This causes the rotor to rotate.

Motors are protected from overheating to prevent insulation failure, moisture formation, and oil breakdown. Line fuses and circuit breakers are designed to protect the circuit only; they protect the motor from too much current. Hermetic motors are equipped with some type of thermal overload device usually designed to be fastened directly to the compressor housing. If the compressor motor is not equipped with a built-in thermal overload, separate protection must be provided in the circuit for the motor. To provide this protection, magnetic motor starters come equipped with overload relay which consists of a heater element installed in the motor circuit and set of contacts installed in the holding coil circuit.

Reference:

1. *Principles of Refrigeration*
2. *Modern Refrigeration and Air Conditioning*

Procedure: After having studied the above information and reference material, do the following assignment.

Assignment:

1. What one big advantage does the polyphase motor have over the single-phase motor?
2. Will a single-phase induction motor start under load?

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose and location of pressure gages.
2. Know how to read a pressure gage.
3. Know how to select the proper gage for a boiler.

Information: The modern pressure gage goes back to 1849 and a French scientist, Eugene Bourdon. He was coiling copper tubing to make a still. In the process, one side was flattened by accident. In order to save the coil, he filled it with water and applied a force pump. He thought that hydraulic pressure would cause the tubing to pop back into shape. But, because the tubing was coiled, instead of going back into its original shape, it started to uncoil. The more pressure he applied, the more it would unwind; and as the pressure was released, it coiled back up. Bourdon didn't shout, "Hallelujah, I've got a pressure gage!" He did make notes of what he observed. This was the idea that was the beginning of our modern pressure gage. Bourdon's findings were recognized and the tube inside a pressure gage is called a Bourdon tube.

Boiler plants have pressure gages to indicate all the various pressure an operator needs to insure safe and efficient plant operation. They will include suction and discharge pressures on fuel and water lines, air pressure, gas pressure, and steam pressure.

Pressure gages are calibrated in pounds per square inch. This is the pressure above atmospheric pressure and is known as gage pressure. Absolute pressure is gage pressure plus atmospheric pressure.

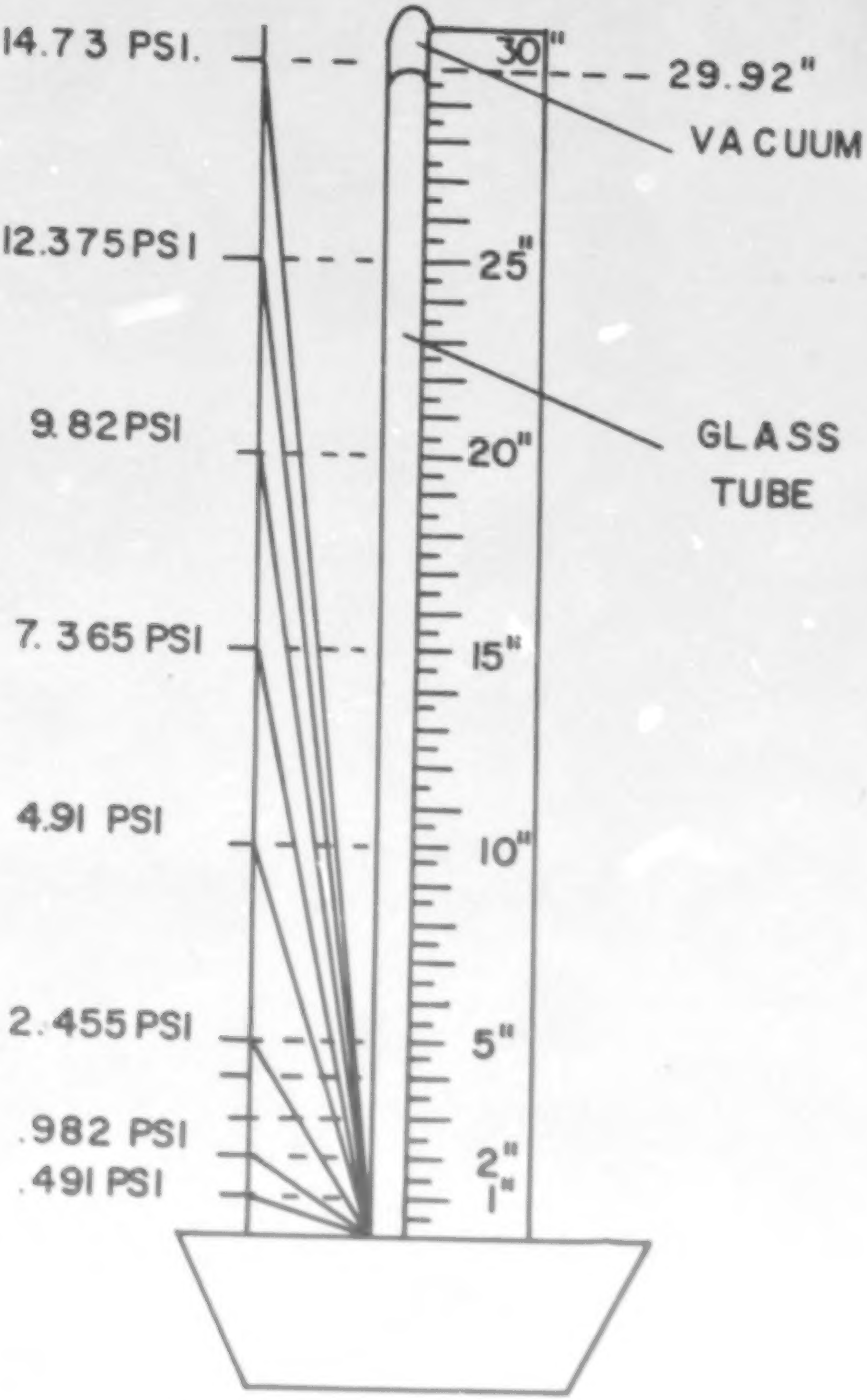
A pressure gage with its pointer pointing to 50 on the face of a gage would be read as 50 pounds per square inch. This is written as 50 p.s.i. or 50 p.s.i.g. If an operator were asked how much pressure was on the above gage, he would answer 50 pounds.

A vacuum gage is calibrated in inches of mercury below atmospheric pressure. A vacuum gage with its pointer pointing to 4 on the face of a gage would be read as 4 inches of mercury below atmospheric pressure. This is written as 4" Hg. If an operator were asked how much suction he had on the above gage, he would reply 4".

Remember:

Pressure gage is read in pounds
Vacuum gage in inches

Figure XVI-A-1-1 may help you to understand what is meant by inches of mercury below atmospheric pressure.


14.73 PSI.
29.92"
30"
VACUUM
12.375 PSI
25"
GLASS TUBE
9.82 PSI
20"
7.365 PSI
15"
4.91 PSI
10"
2.455 PSI
5"
.982 PSI
2"
.491 PSI
1"

1" MERCURY = .491 PSI

Figures XVI-A-1-2 and XVI-A-1-3 are examples of gage faces indicating the standard ranges possible. Note how graduations on faces will vary. For example, on a gage range 0 to 30 p.s.i., each graduation is 1/2 pound and the range 0-300 p.s.i., the graduations are in 5 p.s.i. steps.

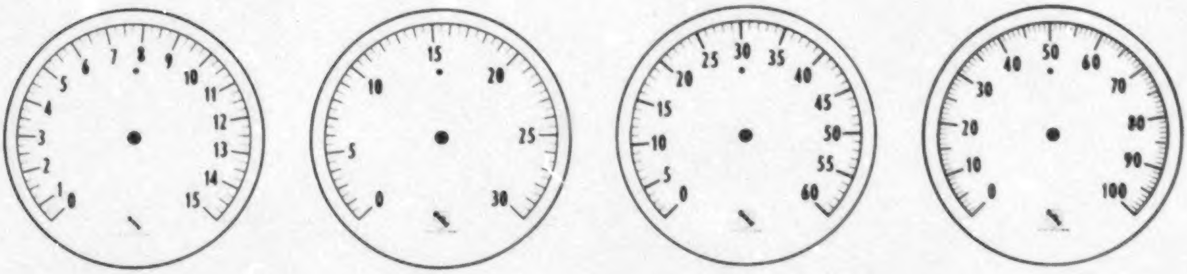
A boiler steam-pressure gage should have a range of two times the safety valve setting. It should never be less than one and one half times the safety valve setting. This means that when ordering a new boiler pressure gage, it is necessary to know your safety valve setting.

The location of pressure gages in a plant will depend on their application. For example:

1. Feed water – one gage on suction side of feed water pump; one on discharge side.
2. Fuel oil – one gage on suction side of fuel oil pump; one on discharge side.
3. Boiler pressure gage – located so that it is plainly visible to the fireman. The line feeding the pressure gage comes off the highest part of the boiler steam drum.

Pressure and vacuum gages are also used in air conditioning and refrigeration systems. They are like helpers telling the operator what is happening in the cycle and what he must do to keep things running smoothly.

Regardless of where the pressure or vacuum gage is used, the pressure gage will be read in p.s.i. and the vacuum gage in inches.



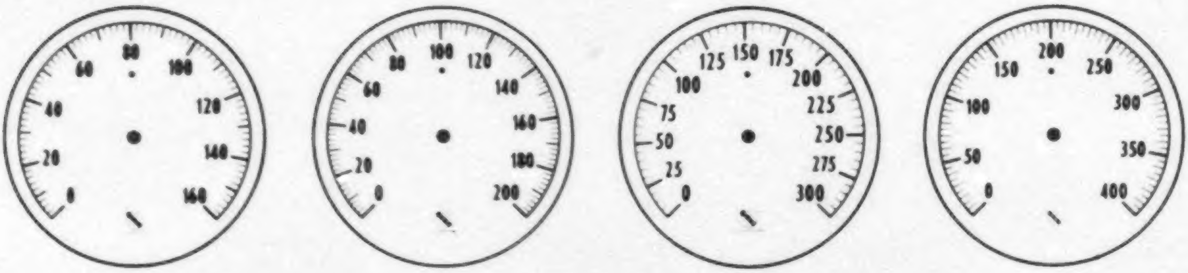
0 to 15 p.s.i.

0 to 30 p.s.i.

0 to 60 p.s.i.

0 to 100 p.s.i.

Fig. XVI-A-1-2


0
20
40
60
80
100
120
140
160
0
20
40
60
80
100
120
140
160
180
200
0
25
50
75
100
125
150
175
200
225
250
275
300
0
50
100
150
200
250
300
350
400

0 to 160 p.s.i.

0 to 200 p.s.i.

0 to 300 p.s.i.

0 to 400 p.s.i.

Fig. XVI-A-1-3

References:

1. *Low Pressure Boilers*
2. *Steam Plant Operation*
3. *Boiler Room Questions and Answers*
4. *Principles of Refrigeration*

Procedure: Study the information and listed references. Do the following assignment and be ready to discuss it in class.

Assignment:

1. How are pressure gages calibrated?
2. What is meant by gage pressure? By absolute pressure?
3. What is meant by the range of a pressure gage?
4. What range must a boiler pressure gage have?
5. Explain why the range of a boiler pressure gage is so important.
6. Where is a boiler pressure gage located and where does it connect to?
7. How are boiler pressure gages protected from live steam? Explain why.
8. Explain where pressure gages are found in the boiler plant and the purpose they serve in these locations.
9. How are vacuum gages calibrated?

Objectives: Upon completion of this lesson, the student will:

1. Know the purpose and location of a manometer.
2. Be able to read a manometer.

Information: In Unit VII-C-1, we discussed draft and its measurement. It should be reviewed before you proceed with this assignment.

As was previously mentioned, the U-tube manometer is the simplest type of pressure-measuring device. The inclined U-tube is more sensitive and gives more accurate readings. When placing the tube on an incline, the fluid will move a greater distance for a given pressure change. The rise in the inclined leg will usually be 1 inch in 10. A special light oil is used in the gage to cut down effects of capillary action. It may be colored red to make it easier to read.

Manometers are often used in air conditioning and refrigeration systems to measure static pressure in air ducts as well as total pressure.

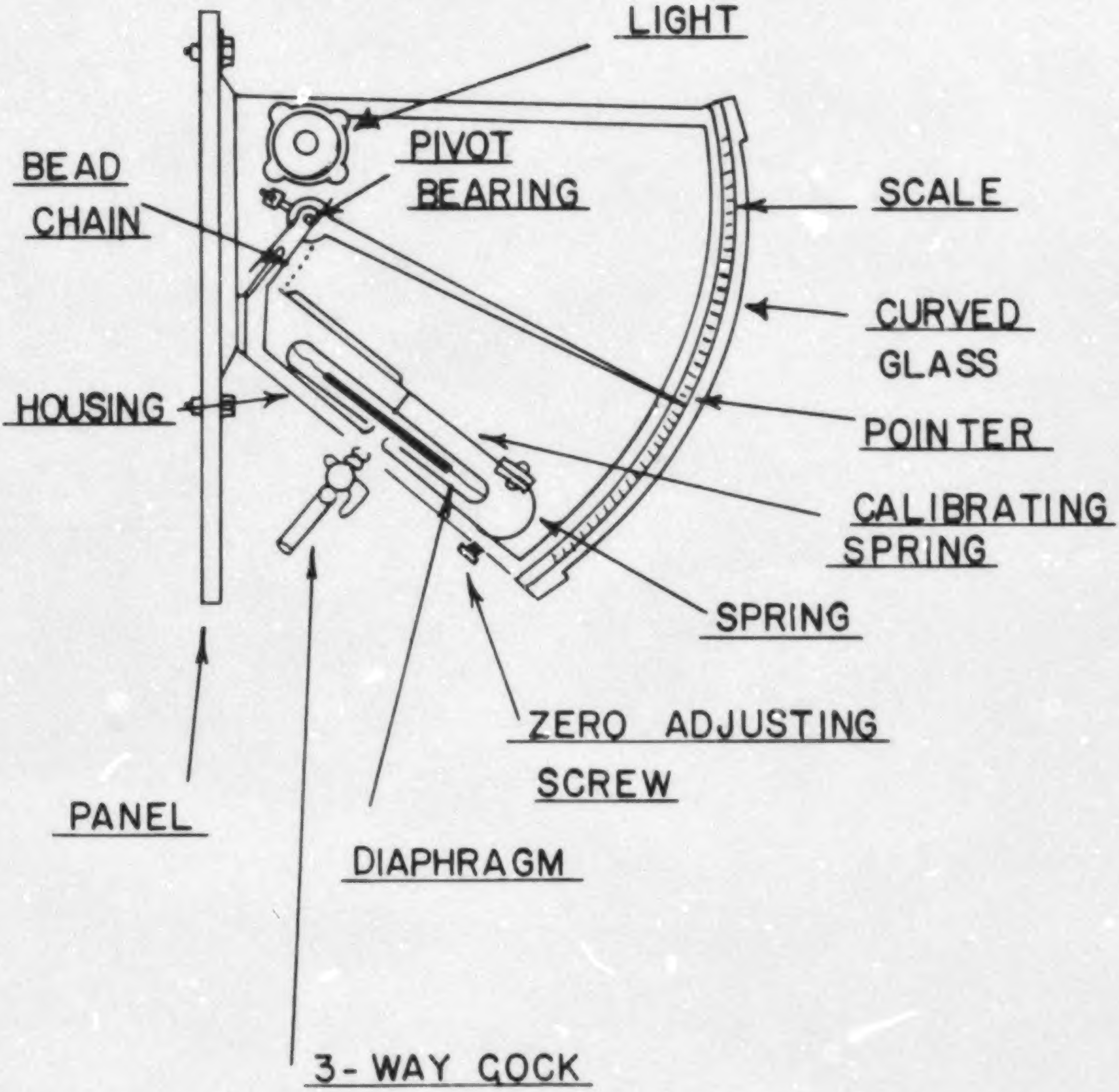
We know that air exerts pressure and will be present in duct work. Since this pressure does not depend on air movement, it is known as stationary or static pressure.

When air is in motion, the pressure is greater than when it is standing still. This is known as velocity pressure. The static pressure plus the velocity pressure is known as total pressure.

Draft gages are located in the boiler room and are usually mounted on the panel board with all the other gages and instruments necessary to operate the boiler safely and efficiently.

The diaphragm air pressure gage, Figure XVI-B-1-1 is used in most modern plants because it is sensitive and reliable. It will indicate small pressure differences and it requires no liquid.

Draft gages are calibrated in inches of water.


LIGHT
PIVOT BEARING
BEAD CHAIN
SCALE
CURVED GLASS
HOUSING
POINTER
CALIBRATING SPRING
SPRING
ZERO ADJUSTING SCREW
PANEL
DIAPHRAGM
3-WAY COCK

DIAPHRAGM PRESSURE GAUGE

Fig. XVI-B-1-1

WHAT ARE THE FOLLOWING DRAFT GAGE READINGS

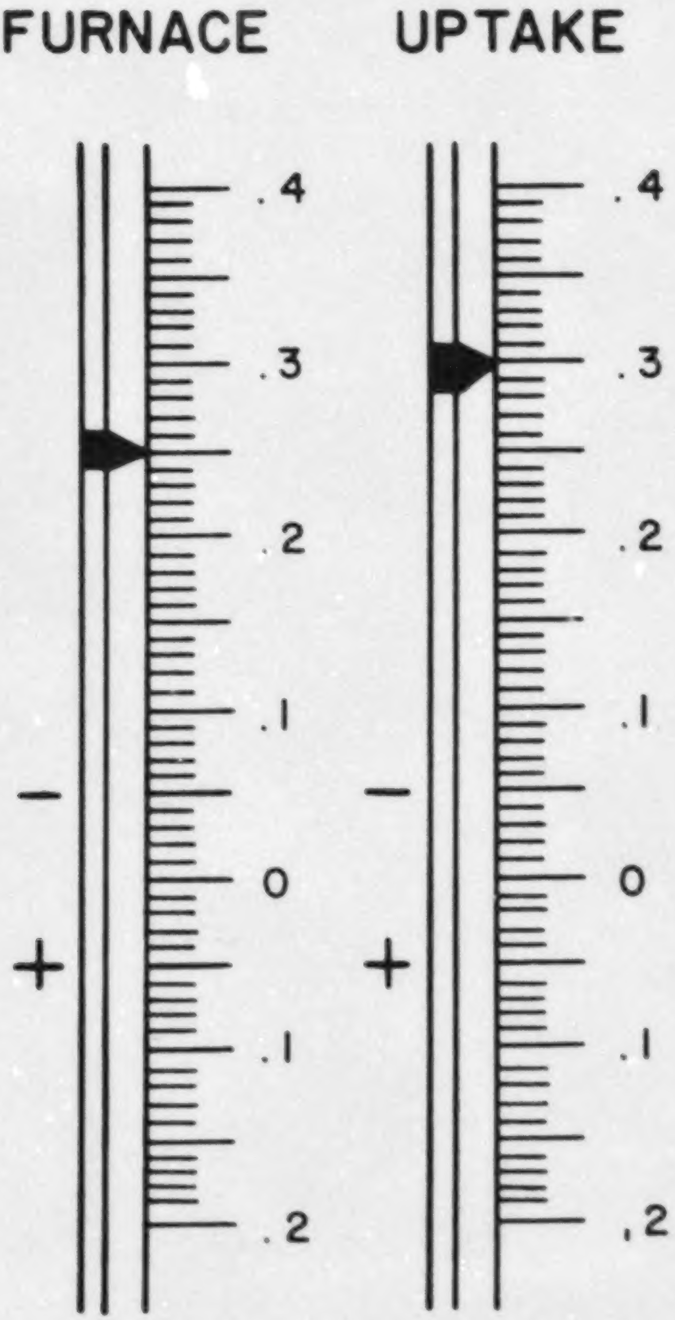

FURNACE
UPTAKE
.4
.3
.2
.1
0
.1
.2
.4
.3
.2
.1
0
.1
.2
–
+
–
+

Fig. XVI-B-1-2

References:

1. *Boiler Room Questions and Answers*
2. *Principles of Refrigeration*
3. *Low Pressure Boilers*

Procedure: Study the information and references; then do the following assignment and be prepared to discuss it in class.

Assignment:

1. What is the purpose of a manometer?
2. List the three basic types of draft gages.
3. Describe the operation of a diaphragm type draft gage.
4. How are manometers calibrated?
5. How would you define the following:
    a. Static pressure
    b. Velocity pressure
    c. Total pressure

Objectives: Upon completion of this course, the student will:

1. Know the purpose and types of thermometers in boiler plants.
2. Be able to read a thermometer and interpret its meaning.

Information: The safe and efficient operation of a boiler plant depends on control instruments. They will give indications of operating conditions. By logging the various readings, they allow the operating personnel to check the efficiency of plant operation. Thermometers fall in the category of control instruments.

Thermometers fall into two broad classifications:

1. Liquid in glass thermometers
   a. mercury-filled (Fig. XVI-C-1-1)
   b. alcohol-filled (Fig. XVI-C-1-2)
2. Bourdon tube
   a. liquid-filled (Fig. XVI-C-1-3)
   b. vapor pressure (Fig. XVI-C-1-4)
   c. gas-filled (Fig. XVI-C-1-5)

Thermometers are calibrated in degrees Fahrenheit (°F) or degrees centigrade (°C). The fixed points are as follows:

Freezing point 32° F. – 0° C.
Boiling point 212° F. – 180° C

Most thermometers used in the boiler plant are calibrated in ° F.

The liquid in glass thermometers expands when heated and contracts when cooled.

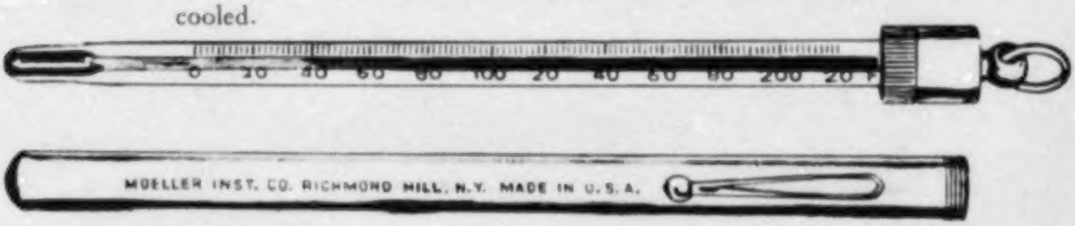

0 20 40 60 80 100 20 40 60 80 200 20 F
MOELLER INST. CO. RICHMOND HILL, N.Y. MADE IN U.S.A.

Fig. XVI-C-1-1
Mercury-filled glass thermometer

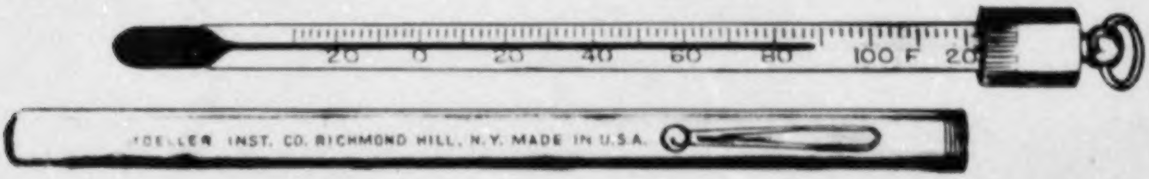

20 0 20 40 60 80 100 F 20
OELLER INST. CO. RICHMOND HILL, N.Y. MADE IN U.S.A.

Fig. XVI-C-1-2
Alcohol-filled glass thermometer

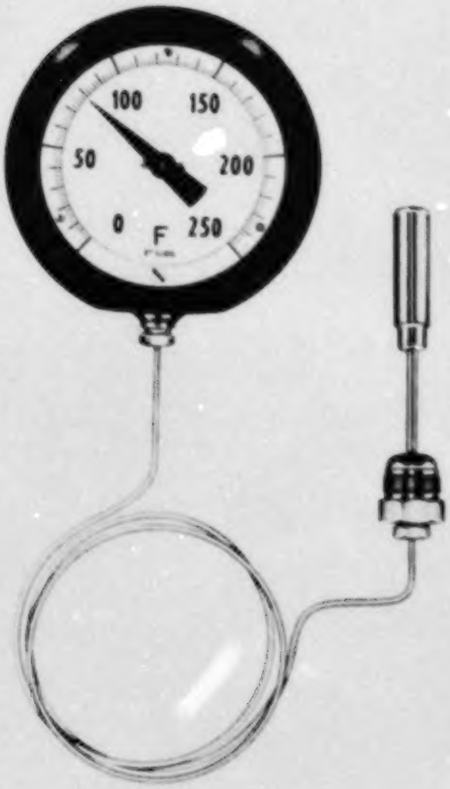

100
150
50
200
0
F
250

Fig. XVI-C-1-3
Liquid-filled bourdon tube

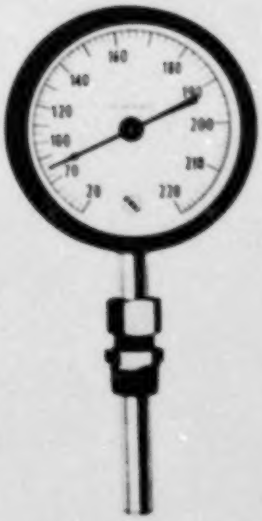

160
180
140
120
200
100
210
70
220

Fig. XVI-C-1-4
Vapor pressure bourdon tube

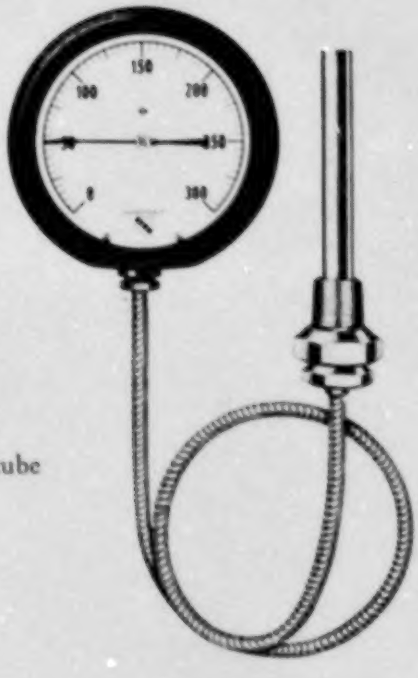
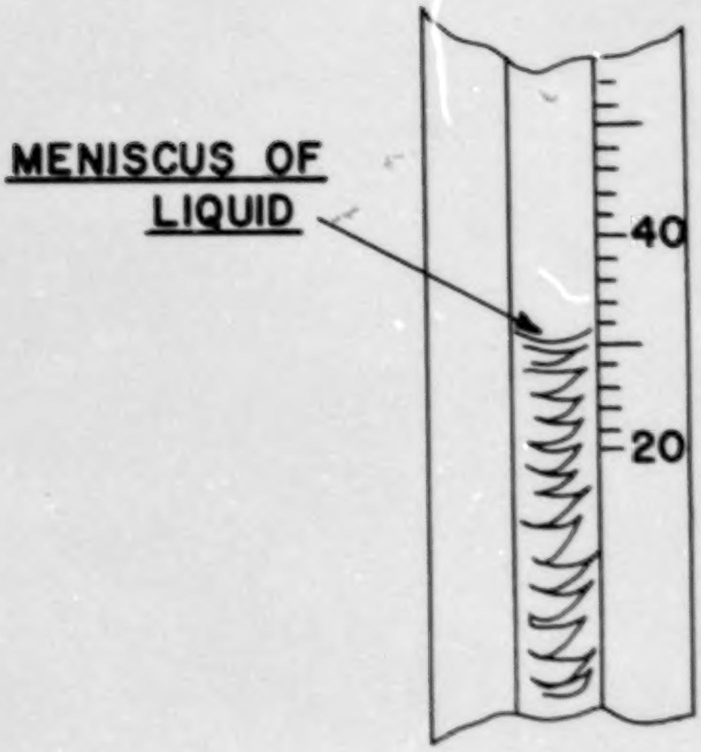

150
100
200
250
0
300

Fig. XVI-C-1-5
Gas-filled bourdon tube

The bulb located at the bottom and part of the capillary tube (called the stem) are filled with the liquid. The rest of the capillary tube is usually filled with vapor from the liquid mixed with an inert gas. The tube is sealed at the top. The temperature readings can be taken by noting the position of the meniscus of the liquid in the capillary tube (Fig. XVI-C-1-6).



ENLARGED VIEW OF GRADUATED CAPILLARY TUBE

Fig. XVI-C-1-6

The liquid-filled Bourdon tube type thermometer can best be explained by looking at Fig. XVI-C-1-7. The bulb (1), the capillary tube (2), and the Bourdon tube (3) are all filled with liquid. The thermal expansion of the liquid in the bulb is responsible for the pressure exerted on the Bourdon tube causing the pointer to register the temperature on the face of the gage. Note that this is not a pressure reading but a pressure that is converted to a temperature reading.

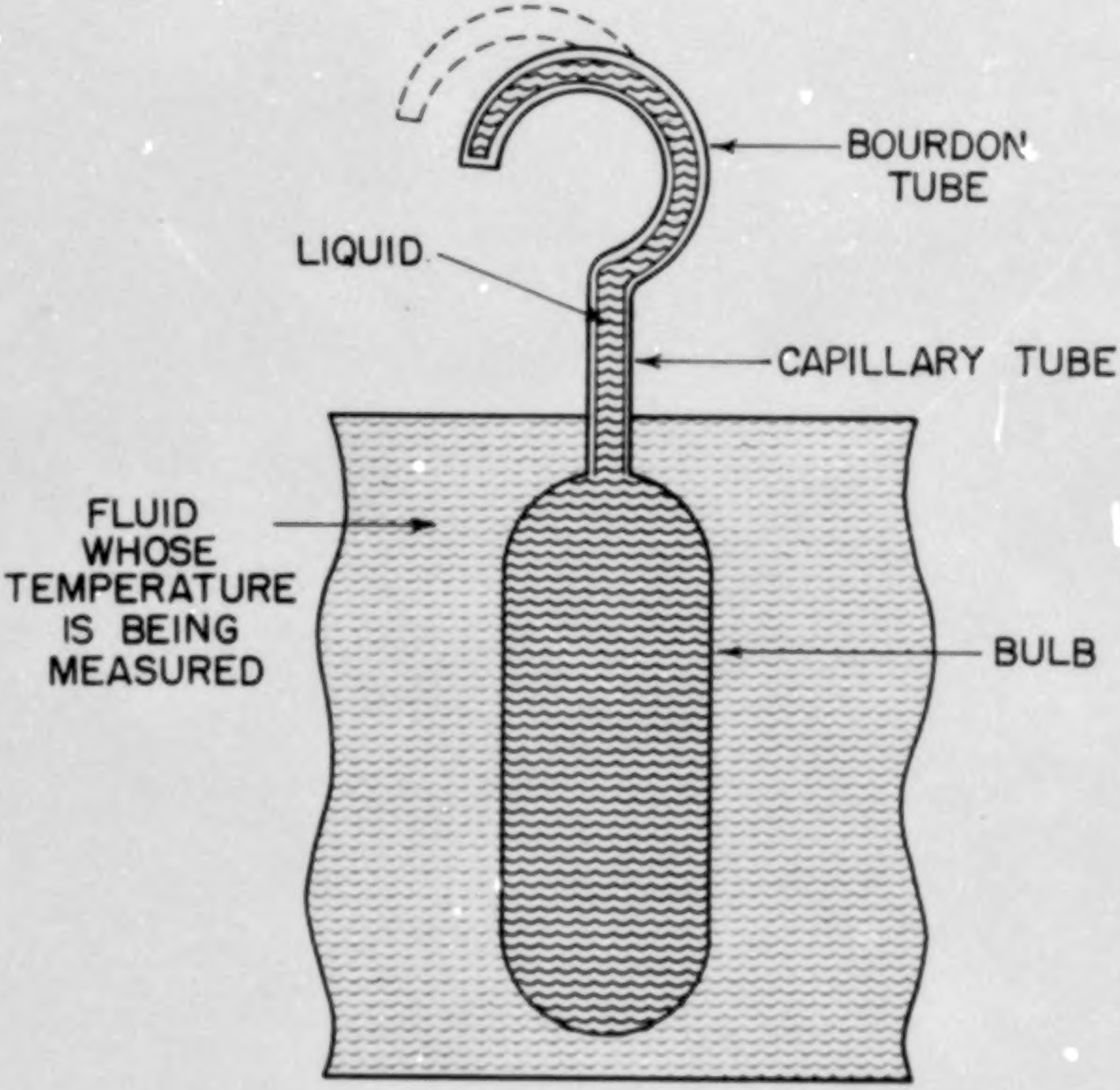
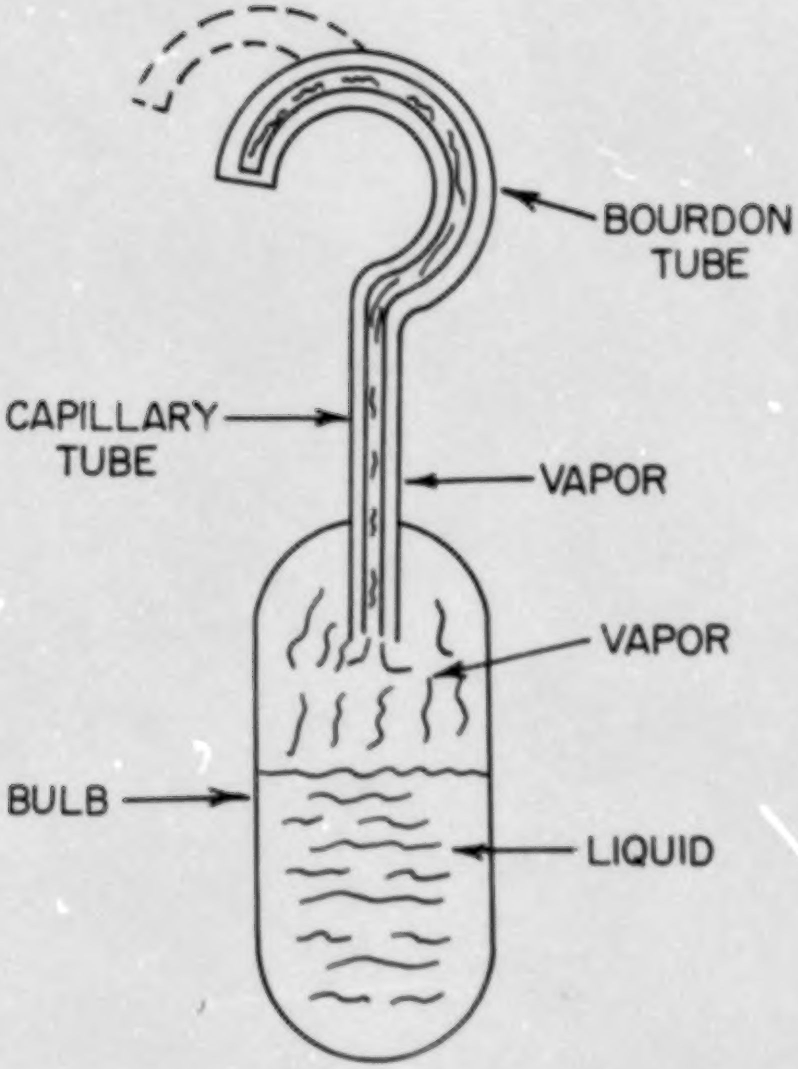

BOURDON TUBE
LIQUID
CAPILLARY TUBE
FLUID WHOSE TEMPERATURE IS BEING MEASURED
BULB

Fig. XVI-C-1-7

SCHEMATIC LIQUID FILLED THERMOMETER


BOURDON TUBE
CAPILLARY TUBE
VAPOR
VAPOR
BULB
LIQUID

VAPOR PRESSURE THERMOMETER

Fig. XVI-C-1-8

The vapor-pressure thermometer is shown in Fig. XVI-C-1-8. The bulb (1) is only partially filled with liquid. The capillary tube (2) and Bourdon tube (3) are filled with vapor. The pressure exerted on the Bourdon tube depends on the temperature of the free surface of the liquid in the bulb. It has the advantage over the liquid-filled Bourdon tube thermometer in that when properly installed capillary tubing up to 200 feet may be used.

The gas-filled thermometer is much like the liquid-filled type. It depends on the thermal expansion of the gas that fills the bulb, capillary tube, and Bourdon tube. Nitrogen gas is most commonly used. Like the vapor-pressure thermometer, there is little restriction in the size of the capillary tube.

References:

1. *Boiler Room Questions and Answers*
2. Manufacturers' catalogs

Procedure: Study the information and listed references; then do the following assignment and be prepared to discuss it in class.

Assignment:

1. What purpose do you think thermometers serve in a boiler plant?
2. How are thermometers classified and give examples of each.
3. Can you see any advantage of using one type over another?
4. What causes a meniscus in a glass liquid-filled thermometer?
5. Can degrees Fahrenheit be converted to degrees Centigrade?
6. Which scale of temperature measurement do we generally find in boiler plants?

Thermocouple

Assignment XVI-D-1

Objective: Upon completion of this lesson, the student will know the purpose of thermocouples and how they work.

Information: The thermocouple consists of two wires of dissimilar metals of different electrical conductivity. They are welded together at one end and sealed in a porcelain tube. Wires connected to this tube may then be connected to a galvanometer or to some form of amplifying device in a control circuit.

Fig. XVI-D-1-1 shows a schematic of a simple thermocouple circuit.

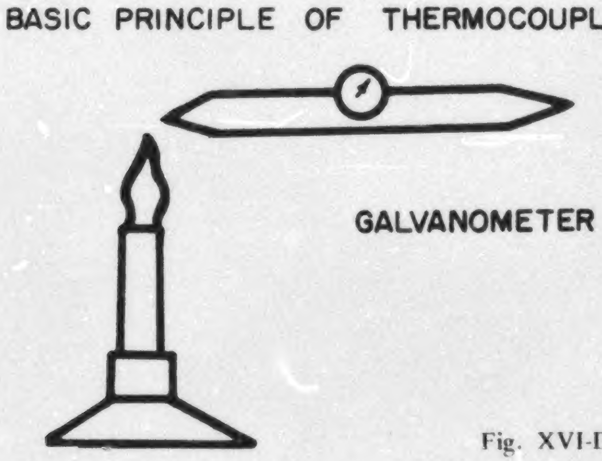


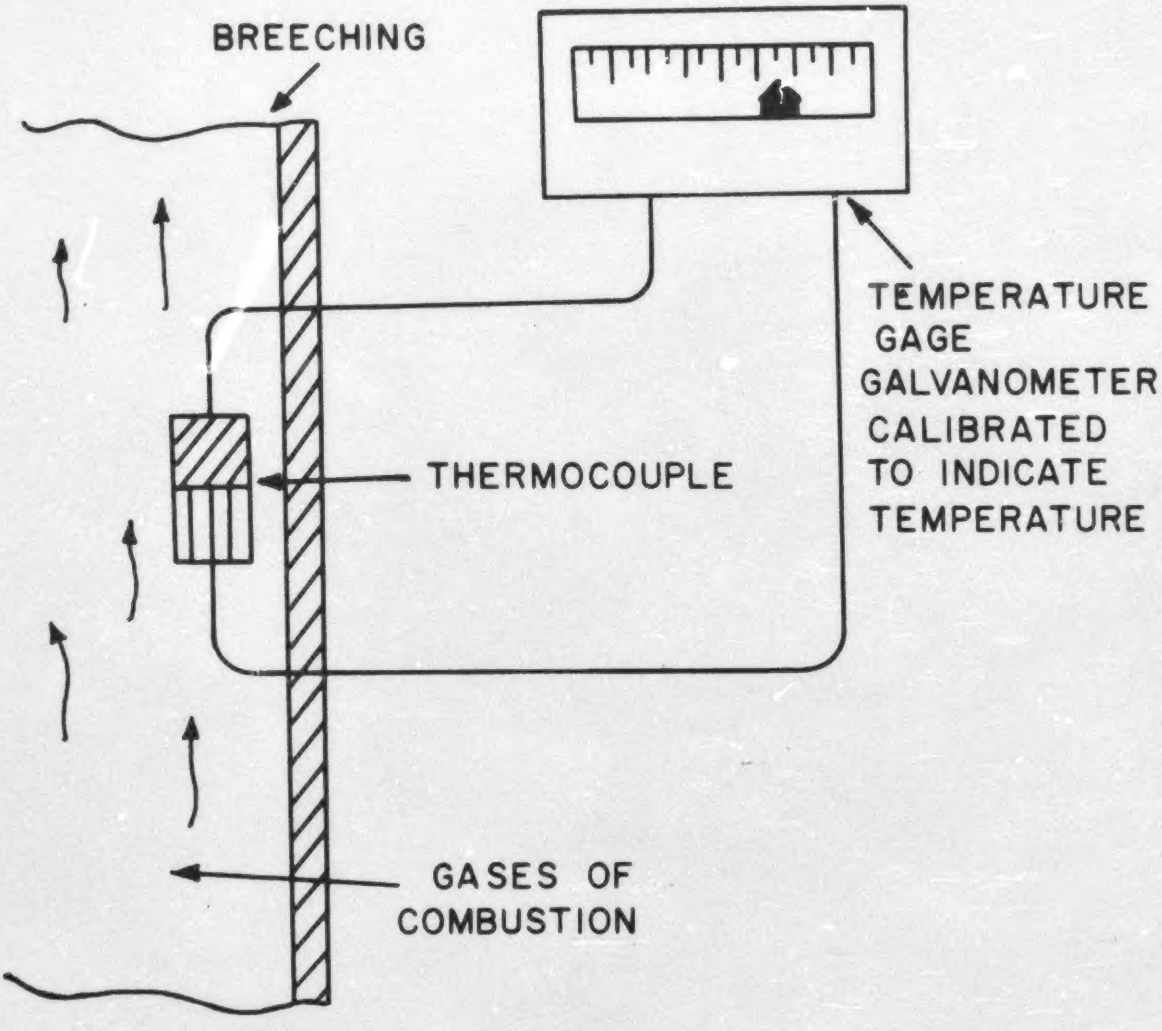
Fig. XVI-D-1-1

The amount of electromotive force depends on the difference between the temperature of the two junctions and the type of materials being used for conductors.

Fig. XVI-D-1-2 shows how the thermocouple is being used to measure flue gas temperatures. One end of the porcelain rod (hot junction) is exposed to the heat of the flue gas. As this heat is picked up, a very small electric voltage is induced. This voltage is proportional to the difference in temperature between the hot junction and the cold junction (where the rod connects to the leads.)

This current flows through the circuit and moves the indicator on the galvanometer. The dial of the galvanometer has been calibrated to read degrees.

If the thermocouple was being used in a control circuit, the current flow would be sent to an amplifier which would send out a stronger signal that could then be used.


BREECHING
TEMPERATURE GAGE GALVANOMETER CALIBRATED TO INDICATE TEMPERATURE
THERMOCOUPLE
GASES OF COMBUSTION

SCHEMATIC OF PYROMETER

Fig. XVI-D-1-2

The advantages of using a thermocouple to measure temperature are:

1. Accurate readings.
2. Good over wide range with rapid readings.
3. Fairly low cost.
4. Can be used for many applications.
5. Can be centrally located taking reading from many remote locations in the plant.

References:

1. *Boiler Room Questions and Answers*
2. *Elementary Steam Power Engineering*
3. *Combustion Engineering*
4. *Steam, Its Generation and Use*

Procedure: After having read the information, study the listed references, do the following assignments, and be prepared to discuss it in class.

Assignment:

1. Briefly explain how a thermocouple works.
2. Explain what is meant by a hot junction. A cold junction.
3. What causes electromotive force to flow?
4. List some advantages of a thermocouple.
5. Do we have any thermocouples recording temperature in our boiler room? If the answer is yes, list them.

Objective: Upon completion of this lesson, the student will know the types, purpose, and location of flow meters.

Information: Flow meters are used to determine the rate of flow, which is the amount of fluid that flows past a given point at any given instant.

Meters designed to measure rate of flow include differential-pressure meters, variable-area meters, and weir, flume, and open nozzle meters.

Differential-Pressure Meters

In order to measure rate of flow by differential pressure, there must be a method of creating two different pressures. This can be done by placing a restriction in the pipe line that forces the fluid through a reduced area. There are three ways in which this is done. The simplest pipe line restriction for flow metering is the orifice plate which is a thin, circular metal plate with a hole in it. Depending upon the fluid to be measured, this will determine the kind of orifice plate to be used.

A second more accurate method is the use of a Venturi tube, which is a specially shaped length of pipe resembling two funnels joined at their smaller openings. This method is used for large pipe lines. It is more expensive and difficult to install.

A third method is the flow nozzle, which is half of a Venturi tube; it is not as expensive and difficult to install.

Variable-Area Meters

There are two types of variable-area meters: the rotameter, in which the area is varied by a float in a tapered tube, and the valve-type area meter, in which the movement of a self-positioning valve varies the area.

Comparing the variable-area meter with the differential-pressure meter, one is restricted to a fixed size and the other varies with the rate of flow.

Weirs, Flumes, and Open Nozzle Meters

Weirs, flumes, and open nozzles are elements used for measuring rate of flow in an open channel.

References:

1. *Elementary Steam Power Engineering*
2. *Instrumentation*

Procedure: Study the listed references and do the following assignment.

Assignment:

1. What is the simplest pipeline restriction for flow metering?
2. The most accurate method of flow metering is by using what kind of restriction in the pipeline?
3. Describe the three different kinds of pressure taps used in conjunction with the orifice plate.
4. What are the two types of variable-area meters?
5. Describe and explain three methods used for measuring rate of flow in an open channel.

Objective: Upon completion of this lesson, the student will know the types, purpose, and location of recorders.

Information: The advancement of science and technology has been accomplished by a continuous development of instruments for measurement and control. The technology of using instruments to measure and control the physical and chemical properties of materials is called instrumentation.

This assignment specifically covers recorders, which is that part of instrumentation dealing with the measuring of a substance.

The recorder can be linear or circular and large or small. It may have strip charts or circular charts. It may be mechanical, electrical, or a combination of both. Some recording instruments are limited to one measured variable; others accommodate many records.

Recorders are used throughout the modern world. The development and progress of industry has relied on the development of instrumentation. The use of recorders can be found throughout industry to measure flow, pressure, temperature level, humidity, and electricity. Without some means to record these variables, our modern world could not function in its customary way of providing us with our high standard of living.

Some examples of the use of recorders in steam plants are steam flow, steam pressure draft, flue gas analyses, and boiler water level.

Process instrumentation in industry is used to record temperatures, pressures, and flows; it increases standards and quality control.

The use of recorders for environmental control is becoming more widely used, not only by private industry, but by state and federal agencies.

References:

1. *Instrumentation*
2. *Combustion Engineering*
3. *Steam Plant Engineering*

Assignment:

1. Indicating instruments have one feature in common – a scale calibrated in units of the measured variable. What does this mean?
2. In your own words describe what a recording instrument does and tell why you think this is important.
3. Give some examples of recording devices and tell what they would be used to record.
4. Why has industry become so dependent on recorders?
5. Recorders can be mounted on panel boards or mounted locally. Describe different methods of mounting recorders.

Objectives: Upon completion of this lesson, the student will:

1. Know how to take over a shift.
2. Know the routine duties of a boiler operator.

Information: The watch engineer or fireman must be prepared to take over a shift and follow a certain procedure. This procedure is important for him to follow so that the boiler plant will be run safely and efficiently. The following numerical order is the procedure that he should follow:

1. Report to work 10 minutes early to relieve the watch engineer.
2. Check water level in boiler by blowing down water column and gage glass.
3. Test low water cut-off control.
4. Inspect and check feed pump, bearings, lube oil level, packing glands, excessive vibration, and feed pump pressure. Inspect and check fuel oil pump, fuel oil pressure bearings, and excessive vibration.
5. Check Chief Engineers Log for outstanding instructions.
6. Check and listen for any unusual noises or steam leaks.
7. Check water level in open type, feed-water heater or make-up feed tank.
8. Check burner and fire for correct flame including fuel temperatures and pressures.
9. Walk around the boiler room and make sure that all machinery is in good operating condition.
10. Check and determine that the fuel supply is adequate.

The routine duties of the boiler operator are clearly outlined in the State Rules and Regulations, which are enforced by the Department of Labor, Mechanical Inspection Bureau. They state that at no time shall the boiler plant be operated in an unsafe manner. The duties of the boiler operator will vary from plant to plant, but there are certain duties which will always remain the same. The following is a list of those duties and responsibilities:

1. Maintain the proper water level in the boiler at all times.
2. Never leave the boiler room for a period longer than that which will not be considered unsafe.
3. Carry out the Chief Engineers written or verbal instructions.
4. Maintain the correct operating steam pressure.
5. Test the low water cut-off control.
6. Test and maintain the feed water regulator in good operating condition.

7. Maintain the burner in good operating condition.
8. Maintain the correct fuel pressures and temperatures.
9. Keep a record of the fuel oil on hand.
10. Check and maintain the amount of make-up feed being used. Always maintain an adequate supply of feed water.
11. Maintain correct feed-water temperature.
12. Periodically inspect feed-water pump.
13. Periodically inspect fuel oil pump.
14. Periodically check draft fans.
15. Maintain the proper draft in the boiler.
16. Check fire in furnace periodically.
17. Follow chief engineers instructions for correct feed-water treatment and boiler blow-down.
18. Use soot blowers when scheduled.
19 Stay alert for any unusual occurrences such as steam load changes, steam leaks, low water in the boiler, and machinery failures.
20. Always operate the boiler plant in a safe and efficient manner.

References:

1. *New Jersey Rules and Regulations*
2. *Boiler Room Questions and Answers*
3. *Low Pressure Boilers*

Assignment:

1. Tell who enforces the boiler plant laws in the state and explain the purpose of these rules and regulations.
2. Why is it important that the boiler operator know the proper procedure for taking over a boiler room shift?
3. Discuss some of the routine duties and responsibilities of a boiler operator. Tell why he must carry out the instructions of the Chief Engineer.

Boiler Plant Startup and Shutdown — Assignment XVII-A-2

Objectives: Upon completion of this lesson, the student will:

1. Know the routine procedure to start up a boiler plant.
2. Know the routine procedure to shut down a boiler plant.

Information: The startup procedure for any boiler plant will vary from plant to plant. It will depend upon such conditions as the number of boilers, the size of the plant, the type of fuel burned, and if the plant is operated automatically or manually. The procedure and method may vary, but the same basic things must be done in as safe and efficient a manner as possible.

Prepare the fuel before "firing up" the boilers. This procedure will be determined by the type of fuel being used.

When gas is used, little or no preparation is necessary except to insure that the correct pressure is at the burner.

In burning coal, an adequate supply of coal must be on hand at the stoker or at the pulverizing mill. In the case of the stoker-fired boiler, a wood fire must be started in the furnace to ignite the bed of coal.

Heavy oil-fired boilers must have the oil circulating and be at the proper temperature before it can be burned. This means that the electric fuel oil heaters will have to be used or lighter grade of oil such as number 2 or 4 used when first lighting off the boiler. All fuel oil strainers should be cleaned as well as the fuel oil burner assembly.

The boilers should be checked for any missing or open inspection openings. All stack coverings should be removed and hand operated dampers should be opened. The correct water level should be showing in the gage glass. The automatic non return valve and the main steam stop valves in the main steam line should be opened and closed. All drains in the main steam lines and header should be opened.

The feed water system should be checked to see that the system is lined up to the boilers and the proper valves are open. Feed pumps, feed water regulators should be inspected. There should be an adequate supply of water in the feed water heater and the make-up feed tank.

The boilers should be purged of all combustible gases before the burner is fired.

Check all the valves on the boilers to insure their proper position: the bottom blown down valve should be closed. The water column, gage glass, steam pressure gage, air cocks and super heater drain valves should be in the open position.

Warm the boilers up slowly to prevent uneven expansion and contraction. Open the automatic non return valve.

Maintain the normal water level in the boiler. When the steam pressure is about 25 lbs. close the air cocks. Open the steam line drain between the non-return valve and the main steam stop valve. Open the equalizing line around the main steam stop valve. When the boilers are up to pressure open the main stop valve. All super heater drain valves should be closed when steam from the plant is being used.

At this time the automatic combustion controls and feed-water regulator should be checked for proper operation along with all boiler-room machinery.

During this period of time the boiler operator has to be constantly alert for any sudden and unusual occurrences, for at no other time will the operation of the boiler plant be more critical than at start-up. All boiler-room machinery must be watched very closely. If automatic controls are used they should be put into operation, and watched very closely. Nothing should be taken for granted.

Shutting down a boiler plant properly will require certain things to be done. This may vary from plant to plant depending upon the size of the plant, length of shut-down and time of year. It must be done so that whenever the plant is started up again there will be no damaged equipment due to improperly shutting down of the plant.

The fuel system should be shut-down and the burners cleaned. How this will be done will be determined by the type of fuel used: coal, oil or gas. A gas system will require little or no attention. A stoker will require cleaning and lubrication. A fuel oil system will require the fuel oil strainers cleaned and the burner cleaned. In the case of a heavy oil system the lines should be blown out by air to ensure that all lines will be clear when starting-up.

The boiler steam stop valves should be closed and all steam line drains opened. The superheater drain should be opened as soon as the boiler is shut-down. When the steam pressure is down to 25 lbs. the air cock should be opened.

While the boiler is cooling down, the water level should be maintained at the normal operating water level. When the boiler has cooled down sufficiently, the feed pump and the feed water system should be shut-down and all valves in the system closed.

When the boiler has cooled off enough to enter it, the fireside should be opened up and cleaned including the breeching and the base of the chimney. After cleaning the fireside, all access doors and panels should be put back and the boiler fireside closed up making sure that all tools have been removed.

The water side of the boiler should be opened up, first making sure that there is no pressure or vacuum in the boiler. All inspection plates and covers are removed and the water side flushed out to remove any mud, sludge or scale in the boiler; it should be closed up tight making sure that all tools and rags have been removed.

The length of time that the boiler plant will be idle and the weather conditions will determine whether the boilers are laid up "wet" or "dry".

When the plant will be subjected to freezing conditions all vessels such as feed-water heaters, boilers, make-up tanks, air tanks along with all water lines must be drained and left empty to prevent damage from freeze-ups.

When shutting down a boiler plant, one thing must be kept in mind and that is to make sure the boilers and machinery can be used again with a minumum of problems and expense.

References:

1. *Low Pressure Boilers*
2. *Boiler Room Question and Answers*
3. *Steam Plant Operation*
4. *New Jersey Rules and Regulations*

Assignment:

1. When starting up a boiler plant after it has been shut down for more than one year, are the boilers required to be inspected by the State of New Jersey? Explain.
2. Explain the reasons why a boiler must be purged before starting the burner.
3. Why does the boiler operator have to be extra alert when he starts up the boiler plant?
4. Name the procedure and steps necessary to get a #6 fuel oil system ready to be used.
5. Explain the wet method of laying up a boiler.
6. Explain the dry method of laying up a boiler.
7. What is meant by a "freezeup" in a boiler plant and how can this be avoided?
8. Why is it necessary and important to clean the fireside and water side of the boiler when shutting it down?

Objectives: Upon completion of this lesson, the student will:

1. Know how to handle a low-water condition.
2. Know how to prevent a furnace explosion.

Information: Many older boilers were equipped with a fusible plug to warn the operator of a low-water condition. Today most fusible plugs have been replaced with low-water, cut-off controls and alarms to help the boiler operator do a safer job. Quite frequently many boilers suffer a low-water condition. This could be due to operator neglect. Control or boiler failure, however quickly and properly the operator handles the condition, will determine to what extent the boiler is overheated and damaged.

Any time the operator cannot see water in the gage glass, a low-water condition exists; he should know the correct procedure to follow immediately. By taking immediate corrective action, he may save the boiler from excessive damage or even prevent the damage from occurring.

The correct method for handling a low-water condition in a boiler is outlined in the references. This will vary to some extent on the type of boiler and the fuel being used. When this condition occurs, every second counts towards saving the boiler from being seriously damaged.

A furnace explosion is the ignition and instantaneous combustion of explosive or highly flammable gas, vapor, or dust accumulated in a boiler setting. In minor explosions, which are referred to as puffs, flarebacks, or blowbacks, flames may blow suddenly for a distance of many feet from all firing and access doors.

Furnace explosions can and do cause serious and costly damage to boiler plants in addition to causing personal injury

The main causes of furnace explosions are lack of adequate purge, human error, flame failure, or a faulty fuel system.

How to prevent a furnace explosion is covered in the references.

References:

1. *Low Pressure Boilers*
2. *Boiler Plant Operation*
3. *Standard Boiler Operators' Questions and Answers*

Assignment:

1. What is a low-water condition in the boiler?
2. Discuss some of the things that could cause a low-water condition?
3. What is the danger of a low-water condition in the boiler?
4. What is the purpose of the low-water, cut-off control and how does it work?

5. What is a furnace explosion?
6. Discuss and name some of the things that could cause a furnace explosion?
7. What relation does the furnace volume have to a furnace explosion?
8. How can a furnace explosion be prevented?
9. Name two types of flame-failure controls.

Objectives: Upon completion of this lesson, the student will know:

1. How to start up a heating plant.
2. What adjustments have to be made.
3. How to operate a heating plant safely.

Information: The operation of a heating plant involves startup, adjustments, and safe operation. Part of this information will be covered in Assignments XVIII-A-1 and XVIII-A-2. To do parts of this assignment, refer to those assignments.

A steam or hot water heating plant requires that the operator be constantly alert and on the job. He must pay a close attention to the heating equipment and machinery and watch the various pressures and temperatures. Serious accidents have occurred because the operator failed to do his job properly.

The feed-water system must be checked out. There must be an adequate supply of water in the boiler including a supply of make-up water.

The fuel system must be checked to determine that an adequate supply of fuel at the right temperature and pressure will be supplied to the burner. The burner should be properly cleaned and adjusted. All hand-operated dampers in the boiler breeching should be opened.

The boiler safety limit controls should be checked to make sure that they will function properly when needed. These controls would include the low-water cutoff control, high-limit pressuretrol, flame failure control, air pressure, and low-fuel temperature control. The low-water cutoff control as well as the flame-failure control should be tested as soon as possible.

A steam heating system must have the water and condensate drained from the steam lines to prevent the rupture of any steam lines because of a water hammer condition.

The adjustments to the pressuretrol on the steam boiler and the aquastat for the hot water heating boiler will be made prior to putting the boiler plant into service. Some minor adjustments may have to be made after the heating plant is in service. Routine safety procedures to operate a heating plant should include the following practices:

a. Blow down the water column and gage glass daily or for each shift.

b. Test the low-water cutoff control daily or for each shift.

c. Test the flame failure control daily.

d. Test the safety valve weekly.

Routine operating procedures to operate a heating plant should include the following practices:

- a. Blowing down the boiler daily.
- b. Cleaning the fuel oil strainers daily.
- c. Cleaning the burner daily.
- d. Checking the various temperatures and pressures daily for the fuel and heating systems.

References:

1. *Standard Boiler Operators Questions and Answers*
2. *Low Pressure Boilers*
3. Manufacturers literature

Assignment:

1. Explain in detail why the boiler operator has to be alert when a heating plant is put into service.
2. What effect will a dirty burner have on a heating plant?
3. Why does all the condensate have to be removed from the steam lines?
4. Name two ways in which the condensate is removed from the heating system.
5. Where does the condensate go to?
6. Why would the aquastat have to be adjusted after the heating plant is in service? What effect does this have on the building temperature?
7. When operating a heating plant, explain in detail what you would do when there is a sudden increase of make-up feed added to the boiler.
8. What are the advantages of returning the condensate to the boiler from the heating system?
9. What effect does air have when it is trapped in a heating system?
10. How is air removed from a steam and hot water heating system?

Ventilating System — Assignment XVII-C-1

Objectives: Upon completion of this lesson, the student will:

1. Be familiar with the routine operating procedures of ventilating system.
2. Know the safety procedures to follow.

Information: The operating engineer is responsible for all heating and ventilating equipment. It is his duty to see that it is operated safely and efficiently. His routine checks or rounds may be made hourly. All operating temperatures and pressures recorded may only require two readings a shift. When temperatures and pressures are recorded at regular intervals, any variation or sudden change would indicate a trouble spot. This allows the engineer to correct a condition before it gets out of hand. When making his rounds, not only does he record temperatures and pressures, but he listens for any unusual noises, looks for proper belt tensions, checks all lubrication, and is aware of any unusual smells. He must operate his plant using all his senses of sight, smell, touch, and sound.

Ventilating ducts go throughout a building bringing fresh, filtered tempered air in and removing stale foul air. Because of this it would be dangerous to have fans running in the event of a fire. Each plant will have a safety procedure to follow in the event of fire. The operator must be thoroughly familiar with it and know where and how to secure any or all his equipment at a moments notice.

Assignment:

1. Why do you think hourly readings of operating temperatures and pressures are important?
2. Why do you think an operator must operate his plant by sight, smell, touch, and sound?
3. Can you explain why a ventilating system must be secured in the event of a building fire?

Objective: Upon completion of this lesson, the student will know the routine duties for operating an air conditioning system safely and efficiently.

Information: The operation of an air conditioning system can be relatively simple or quite complex depending on the size of the system. We will consider a medium size plant as an example of the amount of equipment normally found in such a plant.

The following equipment will require your attention if you wish to run your plant safely and efficiently:

1. The compressor has to be checked for suction pressure and temperature; it is also checked for discharge pressure and temperature. Lubrication and any excess noise or vibrations should also be checked.
2. The condenser and condenser circulating water pumps are checked for proper operation and leakage.
3. The evaporator should be checked for correct operating temperature.
4. The chilled water pumps are checked for leakage and correct operation.
5. All motors are checked for lubrication, heat, and vibration.
6. All fans are checked for correct speed, lubrication, and vibration.
7. All air filters checked for cleanliness.

For safety reasons you should always maintain a clean plant and test the following safety controls frequently:

1. High pressure cutout
2. Low temperature cutout
3. Low oil cutout

Maintain a log with a record of pressures, temperatures, operating conditions, and repairs. It can lead to a standard routine for the safe and efficient operation of an air conditioning plant.

Assignment:

1. Explain in your own words why you think there should be routine duties for an air conditioning plant operator.
2. Why do you think safety is so important in an air conditioning plant?
3. What are the important items you should check for in the operation and safety of an air conditioning plant?

Objectives: Upon completion of this lesson, the student will:

1. Know how to take over a shift.
2. Know the routine duties of the operator.
3. Know the safety precautions that must be followed.

Information: The operator of a refrigeration plant takes over a shift in much the same manner as an operator of a boiler plant which we discussed in Unit XVII-A-1. A certain procedure must be followed for safety and efficiency. That procedure should include the following:

1. Report to work early so that you can check the plant before relieving the operator.
2. Check the suction and discharge pressure on each compressor.
3. Check the suction and discharge temperature on each compressor.
4. Check each compressor for any excess heat or noise.
5. Check the gland or seal on each compressor.
6. Check the lubrication on each compressor.
7. Check the motor driving compressor for heat and correct lubrication.
8. Receiver should be checked for liquid refrigerant level.
9. The tower or cooling pond should be checked for available cooling water; check fan operation.
10. Circulating water pumps, both pump and motor ends, should be checked for correct operation.
11. Check the log book for unusual operating conditions or instructions. When you have completed the above and have found all equipment in satisfactory condition, you should relieve the operator.

The routine duties of the refrigeration plant operator will be as follows:

1. To maintain the correct temperature in the refrigerated sphere.
2. To maintain correct pressures and temperatures on all compressors.
3. To maintain the proper lubrication on all machinery and equipment.
4. To maintain the correct liquid level in the receiver.
5. To locate and prevent leakage of refrigerant.
6. To maintain refrigeration plant log and records.
7. To operate the plant in a safe and efficient manner.

This is by no means a complete list; it may vary from plant to plant or sometimes from day to day within the same plant.

All safety precautions must be strictly adhered to in a refrigeration plant, especially if it is one that has a toxic refrigerant such as ammonia. Some of the safety practices you should become familiar with are:

1. Keep all exits clear.
2. Check fire extinguishers and have them serviced at regular intervals.
3. Emergency equipment such as gas masks, ropes, protective clothing, and tools should be checked and kept in good order.
4. High pressure cut-outs in compressors should be checked at regular intervals.
5. Refrigerant leaks should not be tolerated; they must be repaired.
6. Rags and waste should be stored in proper receptacles.
7. Keep a clean plant. Protect lives; never act in haste.

Assignment:

1. Explain in your own words why you think there should be routine duties for a refrigeration plant operator.
2. Why do you think safety is important in a refrigeration plant?
3. You have just taken over a shift. What are some of the important things you are going to check?
4. You have been asked to check your refrigeration plant for safety. How would you do it?

Objective: Upon completion of this lesson, the student will know the routine service and maintenance required in a boiler plant.

Information: In order to operate a boiler plant safely and efficiently, there are certain routine jobs that must be done on a regular scheduled basis. The Mechanical Inspection Bureau requires that all high-pressure boilers be inspected internally and externally once a year. At this time the boiler and all its fittings and controls are examined to see that they are in proper working order. But what about the rest of the year? Can we just rely on an annual inspection? The answer obviously is no. The safe efficient operation is a 24 hour job, 365 days a year. It does not happen by accident; it happens by careful, intelligent planning. Some routine jobs are listed below:

1. Fuel, oil and lube oil strainer should be cleaned once a shift.
2. Burner tips on boilers on the line should be cleaned once a shift.
3. All boiler room auxiliaries should be watched for proper running temperature and pressures.
4. Grease pump and motor bearings. Completely clean and fresh grease put in once or twice a year.
5. Air compressors – tanks should be blown every shift. Compressor oil changed according to manufacturers suggested procedure.
6. Repack pumps when excessive leakage is evident.
7. Blading on draft fans should be watched and cleaned whenever there is sign of build-up on blades.
8. Oil sumps on turbine auxiliaries should be cleaned and flushed following manufacturers operating procedure.
9. Replace electronic tubes on all controls once a year.

The type of preventative maintenance program will vary with each plant because of the type of equipment in use. Each plant should have some program; some jobs are daily, weekly, monthly, semi-annually or annually. Set a program up for your plant and stick to it. It will save you time, money, and a lot of hard work in the long run.

Reference: *Steam Plant Operation*

Assignment:

1. A lubrication schedule is on page 560 in *Steam Plant Operation*. Using it as a sample, set up a lubrication schedule for the following equipment in our boiler room:
    a. Boiler feed pumps
    b. Low-vacuum pump
    c. Reciprocating-feed water pump
    d. Fuel oil pumps - 3 main
    e. Fuel oil pumps - 3 overhead
    f. Control air compressor
    g. Induced draft fan
2. Why do you think it necessary to clean fuel oil strainers and burner tips daily?
3. How often would you recommend packing the pumps in our boiler room? (Name the pumps you describe.)
4. Why do you think it is important to blow the air compressor tanks daily?

Inspection and Cleaning of Boilers — Assignment XVIII-A-2

Objective: Upon completion of this lesson, the student will know the procedure to follow when cleaning a boiler and getting it ready for inspection.

Information: Be law, high-pressure boilers must be taken off the line once a year, thoroughly cleaned on the fire and water side, and then inspected by a qualified boiler inspector. There are many descriptions of how this is to be done but it is important to stress a few points.

1. When preparing a boiler for inspection, it must be taken off the line, allowed to cool slowly, and certain safety precautions should be taken before any work is done.
    - A. Make sure air cock is open so that there is no vacuum on boiler.
    - B. The steam stop valves are closed and tagged out.
    - C. Feed water stop valves are closed and tagged out.
    - D. After boiler is cool enough to dump and after dumping, close and tag out bottom blowdown lines.
    - E. Before opening steam and water side, hang signs on boiler indicating it is off the line for cleaning and inspection.
    - F. Have men work on boiler in pairs.
    - G. Never use extension cords or drop lights in a steam drum unless they are low voltage or completely sealed.

You may now thoroughly clean the fire and water side. Notify your inspector when you are finished.

Note: All plugs on cross-T's must be removed. All feed-water regulators and low-water cutoffs should be opened. Always be on the alert for signs of oil or pitting in steam drain.

References:

1. *Steam Plant Operation*
2. *A.S.M.E. Code*, Section 7.

Assignment:

1. Why do you think it would be dangerous to open the manhole cover with a vacuum on the boiler?
2. How do you know when a boiler is due for inspection?
3. How is it possible to get oil in a boiler drum?
4. What effects would oil in a steam drum have?
5. Why is it necessary to close and tag out the bottom blow-down valves?
6. What danger is there in using drop lights in a boiler steam drum?

Objective: Upon completion of this lesson, the student will be familiar with the service and maintenance of a heating plant.

Information: Heating plants require the same care as a high-pressure boiler plant. Very often the equipment will be alike. If the heating plant is large and uses #4 or #6 oil, it will more than likely have a strainer similiar to those found in a high-pressure plant. It should receive the same care and treatment. The boilers in heating plants should be kept clean and free of soot. All lines should be tight and free of leaks. The boiler setting should be sealed and tight; brickwork should be in good repair; and fuel oil pump pressure should be checked and cartridge filters replaced annually. Electronic tubes should be replaced annually and all contacts on the control cleaned. A lubrication schedule should be set up and strictly adhered to.

References:

1. *Low Pressure Boiler*
2. *A.S.M.E. Code*, Section 6.

Assignment:

1. Can you list some ways that a high-pressure plant will differ from a low-pressure plant.
2. Why do you think a heating plant should be given the same maintenance that is given a high-pressure plant?
3. Is it possible for a heating boiler to explode? Please explain your answer.

Objective: Upon completion of this lesson, the student will be familiar with some of the routine service and maintenance required in a ventilating system.

Information: It should be quite obvious by now that all systems require some form of service and maintenance to keep them operating trouble-free. The ventilating system is no exception. The duct work should be examined and kept clean of any buildup of dust. Dust is a fire hazard. All filters must be replaced or cleaned at regular intervals depending on the cleanliness of surrounding air. Dirty filters restrict air flow and prevent systems from operating properly. All dampers must be kept lubricated so they will operate freely. All controls must be checked for proper operating conditions. Air control valves must be checked to insure no air leaks. Clean electric controls and check all wires for tightness. All belts must be checked for proper tension and signs of wear. If belts are to be replaced and more than one belt is used, they must be matched sets. This is most important. When ordering belts, you must specify that you want 2-matched or 3-matched or 4-matched belts, etc. Motors are mounted so that you can set both tension and alignment. If either tension or alignment is out, your unit will not operate efficiently; belt wear and breakage will result. In the interest of safety all belts must have guards over them. Whenever making adjustments, the motor main disconnect must be pulled. If you leave the area for parts or tools, the switch should be tagged out. Signs are available stating when the tag was applied, who tagged it, and the caution so it won't be started. The man who tagged out the breaker is the only one who can put it back into service.

Reference: Manufacturers' data sheets

Assignment:

1. What would dirty filters do to a ventilating system?
2. Why do you think it important to remove dust from duct work?
3. What effect would a stuck damper have on system operation?
4. What type of controls do you have on your ventilating system?
5. Why do you think matched belts are necessary?
6. Why must the person who tagged out the breaker be the only one to put it back in service?

Objective: Upon completion of this lesson, the student will be familiar with condenser maintenance and service.

Information: All refrigeration systems using water-cooled condensers require some form of water treatment. Treatment is necessary because all water has some impurities such as minerals, gases, algae, and organic matter. Scale, corrosion, and algae will reduce the efficiency of the system and cause operating problems. Condenser water can be internally treated by using chemicals or externally treated by using water-softening equipment. Some plants will utilize the services of a water-treatment company, which will sell chemicals and service the air conditioning condenser water. They will periodically visit the plant and test the water, adding chemicals when necessary.

Water cooled condensers should not be placed in a location which may be subjected to freezing temperatures. Before a water-cooled condensing unit is shut down and subjected to below freezing temperatures, the condenser coils must be completely emptied of water. This can be done by blowing out the coils with air.

The inside of the tubes on a water-cooled condenser may become coated with foreign materials, such as alkali and scale which will cause poor heat transfer. When this happens, the insides of these tubes have to be cleaned by circulating a cleaning chemical through the tubes. If the condenser is cleaned less than once a year, the tubes may have to be cleaned with an abrasive material. Shell- and tube-type condensers are built in a variety of sizes. Removable heads make it possible to clean the inside of the tubes.

Proper operation of the condensing equipment is required for efficient operation of the system. The presence of air, scale, lack of cooling water, etc. will cause high operating temperatures and pressures in the refrigerant cycle. Operating problems occur when the operating temperatures and pressures are too high.

References:

1. *Doolins Trouble Shooters Bible*
2. *Principles of Refrigeration*
3. *Modern Refrigeration and Air Conditioning*
4. *Principles of Air Conditioning*

Assignment:

1. Why is water treatment required in systems using water-cooled condensers?
2. Explain what an internal or an external treatment is to a water-cooled condenser?

3. What causes high pressures and high temperatures in a refrigeration system?
4. Explain how the above conditions can be corrected.
5. Explain the dangers of a water-cooled condenser being placed outside the building.
6. What effect do non-condensable gases in a condenser have on the refrigeration system?

Objective: Upon completion of this lesson, the student will be familiar with the service and maintenance of an evaporator.

Information: The evaporator is sometimes called a cooling coil, a blower coil, or a chilling unit. Its purpose is to absorb the heat from the surrounding air or liquid by the use of a refrigerant, and to move this heat out of the refrigerated area. Evaporators fall into two categories, flooded and dry expansion. They have been discussed previously.

The capacity of any evaporator or cooling coil is the rate at which heat will pass through the evaporator walls from the refrigerated space or product to the vaporizing liquid refrigerant.

Any fouling of either the external or internal surfaces of the evaporator tends to act as thermal insulation and decreases the conductance factor of the evaporator walls. It reduces the heat transfer.

Fouling of the external surface of air-cooling evaporators is usually caused by an accumulation of dust and lint from the air, which adheres to the wet coil surfaces or by frost accumulation on the coil surface. In a liquid-cooling application, fouling of the external tube surface usually results from scale formation and corrosion.

Fouling of the internal surfaces of the evaporator tubes is usually caused by excessive amounts of oil in the evaporator and/or low refrigerant velocities. At low velocities, vapor bubbles, formed by the boiling action of the refrigerant, tend to cling to the tube walls, thereby decreasing the amount of interior wetted surface. Increasing the refrigerant velocity produces a scrubbing action on the walls of the tube which carries away the oil and bubbles; it improves the rate of heat flow. The refrigerant velocity is limited, however, by the maximum allowable pressure drop through the coil and, if increased beyond a certain point, will result in a decrease rather than an increase in coil capacity.

An excessive pressure drop in the evaporator will cause the suction vapor arriving at the suction inlet of the compressor at a lower pressure than is actually necessary, thereby causing a loss of compressor capacity and efficiency. To avoid unecessary loss in compressor capacity and efficiency, the evaporator must be designed so that the refrigerant experiences a minumum drop in pressure. However it must be sufficient to assure refrigerant velocities high enough to sweep the tube surfaces free of vapor bubbles and oil and to carry the oil back to the compressor.

Evaporator capacity is also dependent upon the circulation, velocity, and distribution of air in the refrigerated space and over the coil. If air circulation is inadequate, heat is not carried from the product to the evaporator at a rate sufficient to allow the evaporator to perform at peak efficiency. It is important also that the circulation of air is evenly distributed in all parts of the refrigerated space and over the coil. Uneven distribution of air over the coil surface causes some parts of the surface to function less efficiently than others and lowers evaporator capacity.

The velocity of the air passing over the coil affects the rate of heat transfer. High air velocities tend to break up the thin film of stagnant air surrounding the tube surfaces.

Superheat is the temperature increase of refrigerant vapor above saturation temperature or above the boiling point of the refrigerant.

It is desirable to utilize as much of the evaporator coil for the purpose of cooling as possible. However, should the flow of refrigerant through the coil be such as would permit some liquid to be still present at the coil outlet, it would be impossible to prevent some liquid from returning to the compressor. To prevent this from happening we must prevent the liquid refrigerant from approaching the end of the coil outlet. This will then result in the last section of the evaporator coil having the purpose of superheating the refrigerant vapor as it leaves the evaporator. The correct amount of superheat is controlled by the thermostatic expansion valve.

References:

1. *Doolin's Trouble Shooters Bible*
2. *Principles of Refrigeration* (Wiley)
3. *Principles of Refrigeration* (Delmar)
4. *Principles of Air Conditioning*
5. *Refrigeration, Air Conditioning, and Cold Storage*

Assignment:

1. Explain the importance of pressure drop in the evaporator?
2. Explain how the refrigerant vapor is superheated in the evaporator coil.
3. Explain the importance of having the proper amount of air at the correct velocity circulating over the evaporator coil.
4. How is an evaporator coil affected externally when it is used for liquid cooling?
5. How does the inside of the evaporator coil become fouled?
6. How does the internal and external fouling of the evaporator coil surfaces affect the system?
7. How does the evaporator coil affect the liquid carry over to the compressor?

Objective: Upon completion of this lesson, the student will be familiar with the maintenance and service of compressors.

Information: The compressor is often referred to as the "heart" of a mechanical refrigeration plant. Without it the system could not function. There are three types of compressors commonly used for refrigeration: (1) reciprocating, (2) rotary, and (3) centrifugal. All three compressor types have certain advantages in their own field of use, but unless they are well maintained, they will not give you the reliable service which is expected and required.

All compressors must be given the proper lubrication to eliminate the wearing and overheating of bearings, internal parts and surfaces. Regardless of the type of compressor, oil must have certain properties: (1) free of moisture, wax and foam; (2) correct viscosity; and (3) free of impurities. The oil level should be checked periodically. Compressors may be splash lubricated and lube oil filters and strainers must be cleaned periodically.

To control the operating temperatures, cooling water is circulated through a water jacket around the piston cylinder walls and cylinder head. The water circulated through the jacket must be free of mud and scale-forming impurities to prevent the cooling system from becoming plugged. Cooling water must be externally treated wherever the water contains excessive impurities.

When suction-line strainers are installed to protect the compressor from contamination, they should be replaced periodically.

Moisture has a harmful effect on a refrigeration system and can cause the oil to break down and lose its lubricating qualities. Moisture can also cause the insulation on the windings of a hermetic-type compressor to deteriorate and fail causing a motor burnout. Any moisture in the system can be removed by the use of a drier in the liquid line, which may have to be replaced periodically.

Refrigeration compressors vary to a large extent. The manufacturer's instructions should be followed for all maintenance procedures. The suction and discharge valves of the larger size reciprocating compressors must be checked periodically for signs of any wear or metal fatigue. Again the manufacturer's instructions should be followed when dismantling and assembling the compressor.

The proper service and maintenance of a compressor can save the owner money and emergency repairs; it is a wise investment in the overall operation of the plant.

References: 1. *Principles of Refrigeration*
References: 2. *Principles of Air Conditioning*
3. *Modern Refrigeration and Air Conditioning*

Assignment:

1. Why is it important to follow the manufacturers instruction for the maintenance and service of a compressor?
2. What qualities should lubricating oil have?
3. What harmful effect will moisture have on a hermetically-sealed compressor?
4. Why should the valves of a reciprocating compressor be checked periodically?
5. How is moisture removed from a refrigeration system?

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